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CHEMICAL ENGINEERING ECONOMICS

BY

CHAPLIN TYLER

Assistant Director, Public Relations Department, E. I. du Pont de Nemours & Company, Formerly Assistant Editor, Chemical & Metallurgical Engineering, Associate, School of Journalism, Columbia University; Research Associate, Chemical Engineering Department, Massachusetts Institute of Technology; Member, American Institute of Chemical Engineers and American Chemical Society

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CONTENTS

CHEMICAL ENGINEERING ECONOMICS

CHAPTER I

CHARACTERISTICS OF THE CHEMICAL AND ALLIED INDUSTRIES

The production of goods can be classified into the following groups:

1. Agricultural production (products of the soil and of animal husbandry).
2. Extractive production (products of the mine, forest, and sea; as for example, coal, metallic minerals, petroleum, natural gas, sulphur; lumber; fish).
3. Factory production.

There is, of course, much integration in these groups. For example, many producers of petroleum refine part or all of their primary crude production. Similarly, many producers of metallic minerals operate smelters and mills for fabricating metals. Looking to the future, it is possible that forestry may become an agricultural pursuit (as, for example, the growth of pulpwood in the South); or that some agricultural operations will be on a factory basis (as, for example, tray agriculture, based on nutrient solutions and a conditioned atmosphere).

Factory Production Classified.—Factory production can be classified into two groups:

1. Production based essentially on change in physical form.
2. Production based essentially on change in chemical form.

Examples of the first class are such manufactures as automobiles, furniture, machinery, shoes, and textiles. Thus, the automobile is an assemblage of hundreds of materials and fabricated parts—metals, wood, glass, fabric, plastics, rubber, finishes, tires—all of which can be identified in the ultimate product. There has been no change of substance, only a change in physical form.

Examples of the second class are such manufactures as synthetic ammonia, dyestuffs, plastics, soda ash, and sulphuric acid. Thus, nitrogen from the atmosphere and hydrogen from water are combined to form an entirely different third substance, ammonia.

Such distinctions as these are perfectly clear. Some industries, however, are not so easy to classify. Thus, in the tanning industry, the hide, though coagulated, does not undergo a complete transformation. The leather "molecule," if one might use such designation, is an addition product of the protein hide substance and the tanning agent. In the petroleum refining industry, some of the refining processes are physical—for example, such processes as dewaxing, filtration, and solvent refining. These are separation processes and involve little or no chemical change. In the cracking process, however, higher hydrocarbons are broken down chemically into lower liquid hydrocarbons, gas, and coke. Polymerization, the converse of cracking, is a recently applied chemical process for producing liquid hydrocarbons from refinery gas. Likewise, the treating processes based on such reagents as sulphuric acid, caustic soda, and sodium plumbite are chemical processes.

Ordinarily, iron smelting is not classed as a chemical industry, yet it depends upon chemical reactions. Similar examples are the smelting of copper, lead, zinc, and other metallic ores. The electrolytic winning of aluminum is just as much a chemical process as the electrolysis of aqueous salt to chlorine, caustic soda, and hydrogen.

Sugar refining is largely a physical process industry, yet chemistry plays an important part in various steps, as in purifying the sirup and in recovering sugar from beet molasses. A similar circumstance is found in the corn products industry. The recovery of starch from the corn is a physical process, assisted by chemical treatment. The conversion of corn starch to corn sugar, however, is a chemical process.

In the cotton textile industry, the basic processes of spinning and weaving are physical, although such finishing processes as bleaching and mercerizing are chemical. In the rayon branch of the textile industry, the processes of fiber synthesis are chemical.

Position of the Chemical Engineer.—The chemical engineer is concerned not so much with finely drawn distinctions between

chemical industry and other industry as with industrial processes that can be resolved into chemical engineering unit operations and unit processes, whether the industry be dyestuffs manufacture, fertilizer manufacture, or sugar refining. Thus, the field of the chemical engineer is much broader than chemicals manufacture, a fact which has been elucidated by Stine.[1]

While the unit operations, which in proper sequence and coordination constitute an industrial process and comprise the field of the chemical engineer, are clearly defined, the industries in which they find more or less complete and recognized application are not quite so easily enumerated because they range from patently chemical engineering industries to those in which the chemical engineer has as yet but slight recognition, and those industries in which the field of chemical engineering has rather definite limitations by virtue of the nature of the industry.

If we were to segregate the industries according to the penetration of chemical engineering, we might follow somewhat the classification indicated in *Chemical & Metallurgical Engineering*, January, 1928. This classification is designed to indicate roughly the degree of penetration of chemical engineering into modern industry.

Group I, in which the penetration is practically complete, would consist of:

Heavy chemicals.
Fine chemicals.
Electrochemicals.
Coal tar products.
High explosives and propellent powders.
Artificial fibers.
Synthetic resins.

In group II the penetration may be said roughly to be something well over 50 per cent, say 60–75 per cent, and in this group we might enumerate:

Coal processing.
Petroleum refining.
Wood distillation.
Sugar refining.
Paper and related pulps.
Cement, lime, and special plasters.
Fertilizers.

In group III are to be found industries in which the penetration of chemical engineering is to date perhaps 50 per cent or less. Here are to be found such industries as:

[1] *Trans. Am. Inst. Chem. Eng.*, p. 45 (1928).

Vegetable oils.
Ceramics and glass.
Paints and varnishes.
Soap.
Leather.
Textiles.
Rubber (possibly should be in group II).

It does not follow from the rough grouping of the industries attempted here, that a specific factory or manufacturing establishment which happens to produce a product in group III actually illustrates by its methods of dealing with its manufacturing problems only a 50 per cent or less application of chemical engineering in another establishment. There are notable exceptions in each of the three groups.

Furthermore, numerous industries involving mechanical and electrical engineering, rather than the operation of chemical processes, present only a limited opportunity for the penetration of chemical engineering. This limitation upon the application of chemical engineering is not fully taken into consideration in the above grouping, but it is highly important in most of the industries of the third group.

The first group, in which almost complete penetration has been effected is essentially chemical in process and product. A scientific basis is recognized within the industries, and the direction and control of operations are in the great majority of cases in the hands of technically trained men. Perhaps because of their close connection with pure chemistry, in which the scene is ever kaleidoscopic, these industries are subject to revolutionary changes. The heavy chemical industry has experienced such changes in the past in the production of sulphuric and hydrochloric acids and is now experiencing another in the production of nitric acid by ammonia oxidation.

The industries of the second group include some of the largest industries in which the chemical engineer is active. The petroleum industry is an infant in the industrial family but a lusty one. It is moving with a constantly increasing acceleration towards a scientific basis, as is evidenced by the organization of the American Petroleum Institute with its large fund for research and by the procession of highly trained engineers who are being drawn into the petroleum industry.

Such a generalization cannot be made with regard to the industries of the third group. With the exception of the rubber industry, the industries comprising this group belong to the class of those which have in the course of generations reached a high state of development as arts rather than technical industries. Nevertheless, there are some outstanding examples of the effect of the activities of the chemical engineer on these industries.

Unit Operations and Unit Processes.—A list of the more important unit operations of chemical engineering would include heat flow, fluid flow, crushing and grinding, mechanical separation, filtration, evaporation, distillation, drying, absorption, crystallization, mixing.[1]

Regarding the unit processes of chemical engineering, Shreve[2] says:

> The principal unit processes are as follows: nitration, esterification, sulphonation, amination by reduction, amination by ammonolysis, oxidation, hydrogenation, hydrogenolysis, alkylation, acetylation, halogenation, double composition, cracking, polymerization (depolymerization), resinification, diazotization and coupling, hydrolysis, hydration, and the Friedel and Crafts reaction.
>
> Most of us have confined unit processes to organic technology, but there is no reason why this helpful system of classification should not include inorganic technology. The chamber process, the contact process, and the air oxidation of ammonia to nitric oxide would be subheads under the unit process of oxidation, with the better opportunity of emphasizing the analogous phases of such reactions—for example, the great amount of heat involved in such chemical changes together with the equipment necessary to handle it.

Magnitude of Chemical and Allied Industries.—Adhering fairly closely to the groupings for the chemical and allied industries suggested by the U. S. Census of Manufactures and by *Chemical & Metallurgical Engineering*, the accompanying statistical summary is given (see Table I).

Depending upon variations in classification, the chemical and allied industries comprise from 15 to 20 per cent of all manufactures, using value of product as a measure. The total of industries included in Table I comprises about 17 per cent of all manufactures.

By-products.—Characteristic of chemical industry is the fact that products other than those primarily desired are often produced. Thus, glycerin is produced with soap; hydrogen is produced with electrolytic caustic soda and chlorine; charcoal, crude methanol, tar, and oils are produced with acetic acid or acetate of lime when wood is distilled; gas, tar, oils, and ammonia-

[1] See Olive, *Chem. Met. Eng.*, **41**, 229 (1934).

[2] *Ind. & Eng. Chem.*, **29**, 1329 (1937).

cal liquor are produced with coke; calcium chloride is produced with soda in the ammonia soda process.

When there is little or no demand for one of these unavoidable products, it is called a waste product. For example, the digester liquors from the chemical pulp industry are largely run to waste. Considerable progress, however, is being made toward their utilization. Most of the carbon dioxide from fermenters and from the ammonia soda process is wasted. A small quantity is used for making solid carbon dioxide refrigerant.

When an unavoidable product is readily marketable but is not normally essential to the profitable operation of the process, the term "by-product" is used although, in a general sense, the term applies to any product other than the one primarily desired. For instance, normally there is a demand for all the glycerin produced by the soap industry. Assuming, however, that the demand for glycerin should cease, the soap industry would continue to operate. Eventually, the price of soap probably would be increased, to make up for the loss of revenue from glycerin.

Sometimes it is difficult to determine which of several products is the principal product. In this case, the products are called joint products. For instance, electrolytic caustic soda and chlorine are joint products. Both are essential to the profitable operation of the process.

Circumstances may alter radically the economic position of a product. Niter cake is an excellent example. Approximately 2 tons of niter cake is produced for each ton of nitric acid (calculated as 100 per cent HNO_3) when nitrate of soda reacts with sulphuric acid. Thus, in the census year 1923, the production of niter cake was 154,087 tons and the production of nitric acid was 77,633 tons. The total value of the niter cake, assuming an average value at the factory of $4.54 per ton, was $699,555, and the total value of the nitric acid, assuming an average value at the factory of $126 per ton, was $9,781,758. In 1923, therefore, the niter cake represented only 6.7 per cent of the total value at the factory of the two products.

By the census year 1935, the production of nitric acid had increased to 122,596 tons, although only 14,000 tons, or 11.5 per cent of it, was made from nitrate of soda, owing to the widespread adoption of the ammonia oxidation process. Incidentally, part of this nitrate of soda was produced synthetically. The total

TABLE I.—STATISTICAL SUMMARY—CHEMICAL AND ALLIED INDUSTRIES
(*U. S. Census of Manufactures*, 1935)

Industry	Number of establishments	Value of products manufactured	Cost of raw materials	Wages paid	Number of wage earners
Baking powder, yeast, and other leavening compounds	46	$32,340,648	$14,603,037	$4,277,962	2,666
Blacking, stains, dressings	167	17,931,563	8,387,199	1,467,345	1,498
Bone black, carbon black, and lampblack	55	14,811,298	5,334,329	1,936,570	1,828
Ceramics	1,350	178,573,018	56,204,132	62,779,006	73,744
Chemicals not elsewhere classified	570	668,697,448	329,350,435	80,480,605	65,838
Coke-oven products	88	238,703,683	180,557,083	21,575,184	16,694
Compressed and liquefied gases	330	42,018,950	11,239,281	4,408,205	3,788
Corn sirup, sugar, oil, and starch	12	98,963,756	67,650,312	8,028,720	6,921
Explosives	74	40,667,200	17,000,618	5,639,358	4,566
Fertilizers	670	140,386,112	93,364,695	10,967,021	17,473
Glass and glassware	213	283,925,061	110,008,152	71,443,178	67,138
Glue and gelatin	74	28,161,033	15,076,298	3,534,418	3,253
Grease and tallow, not including lubricating greases	260	45,207,296	27,304,982	5,418,697	4,784
Ink, printing	191	34,534,951	18,554,558	3,233,728	2,370
Ink, writing	22	3,381,907	1,414,541	379,236	377
Insecticides, fungicides, and industrial and household chemical compounds not elsewhere classified	546	53,429,197	24,343,531	3,401,387	3,466
Leather	384	308,344,763	197,969,858	55,683,471	50,877
Lime and cement	342	143,739,200	51,857,712	26,955,811	28,193
Manufactured gas	520	345,967,324	97,864,353	27,663,273	19,741
Mucilage, paste, and other adhesives, except glue and rubber cement	66	3,632,601	1,646,165	288,569	267
Oil, cake, and meal, cottonseed	458	187,887,305	160,540,022	5,911,625	13,226
Oil, cake, and meal, linseed	25	60,264,331	48,808,968	2,649,697	2,350
Oils, essential	12	3,541,983	2,601,649	219,018	166
Paints, pigments, and varnishes	1,082	416,999,566	231,982,952	32,186,867	27,686
Paper	591	711,793,299	429,113,355	110,200,308	103,345
Petroleum refining	395	1,838,621,913	1,478,224,853	109,610,774	77,402
Pulp	188	167,208,261	96,246,588	23,401,212	23,623
Rayon and allied products	32	185,159,534	64,505,631	50,693,182	50,550
Rubber	465	677,437,237	368,478,339	133,659,754	114,612
Salt	48	29,720,004	10,933,009	4,883,677	4,976
Soap	238	239,152,130	139,423,048	15,339,045	13,911
Sugar, beet and cane	169	498,645,860	425,621,319	24,782,379	26,008
Tanning materials, natural dyestuffs, mordants and assistants, sizes	154	33,638,800	19,704,046	2,636,004	2,651
Wood distillation and charcoal manufacture	60	15,970,917	7,923,459	2,816,417	3,808
Total chemical and allied industries	9,897	$7,789,458,149	$4,813,838,509	$918,551,703	839,796

value of the 27,933 tons of niter cake, assuming an average value at the factory of $18.41 per ton, was $514,247, and the total value of the equivalent quantity of nitric acid, assuming an average value at the factory of $87 per ton, was $1,218,000. In 1935, therefore, the niter cake represented 29.7 per cent of the total value at the factory of the two products.

A comparison between the census years 1914 and 1935 would show an even greater contrast, as in 1914 the average value at the factory of niter cake was only $1.31 per ton. The tremendous increase in value of niter cake from $1.31 per ton in 1914 to $18.41 per ton in 1935 resulted not only from the decrease in supply, but also from the development, about 10 years ago, of smelting processes which require niter cake (or the equivalent, as salt cake) in large quantities. Moreover, the demand for neutral sodium sulphate also has increased, owing to the growth of the kraft pulp industry and the glass industry. As a result, sodium sulphate in all forms has assumed a new importance. Supplementing the output of the chemical industry, large quantities are recovered from the Chilean salt deposits and from various natural sources in the West and in Canada.

Emphasis on Research.—In the chemical and allied industries, the emphasis on research is relatively great. This is not surprising, since many branches of the industry were created by research; as, for example, the dyestuffs, plastics, rayon, high explosives, and nitrogen fixation branches. Moreover, the industry recognizes that research is essential if continued progress is to be achieved.

Within chemical industry proper, the research expenditures are between 2 and 3 per cent of sales, whereas in all manufacturing industry such expenditures are only one-fifth as much. With respect to research in chemical industry, E. M. Allen[1] says:

> Emphasis put on research is one of the outstanding characteristics of the American chemical industry. No other division of industry has been more dependent upon investigation and technical developments. Any firm in the chemical business which does not support an effective research program, soon falls behind its competitors, if indeed, it does not in time suffer elimination. It is, therefore, not strange that a surprisingly large percentage of the income from the sale of chemicals has been expended for research, in order to improve existing processes,

[1] *Textile Bulletin*, **53**, 18 (1938).

devise new and more efficient methods of manufacture, develop new products and render technical service to the consumer. In the inorganic or "heavy chemicals" branch of the chemical industry, approximately $2.25 of each $100 of sales is spent for research, and one well-known firm spends 20 per cent of its net income from sales for research.

Research as a Factor in Change.—Considering the tremendous emphasis on research in chemical industry, one would expect a corresponding amount of change in products, processes, and applications of products and processes. Such is the case. As several authorities have expressed it, the only unchanging thing in chemical industry is change itself. For instance, at the Sixteenth National Exposition of Chemical Industries, New York, December, 1937, the American Chemical Society displayed a group of more than 100 new products which had been put on the market during the preceding two years.

In the Annual Report to Stockholders for 1937, the president of the du Pont Company stated that 40 per cent of the company's total sales volume in 1937 was accounted for by twelve groups of products representing the more important developmental lines during the past 10 years:

> The twelve groups of products in question, with the year of introduction shown in each case for those not in production at the start of the ten-year period in 1928 are as follows: "Duco" finishes; "Dulux" enamels (1930); neoprene (1932); synthetic camphor (1933); "Ponsol" dyes; anhydrous ammonia; synthetic methanol; urea (1935); titanium pigments (1931); viscose rayon; acetate rayon (1929); "Cellophane" cellulose film. These twelve lines accounted for about 40 per cent of the Company's total 1937 sales volume; and their production and sale are now directly giving employment to approximately 18,000 workers, as compared with about 10,700 employees in 1928 in the same groups of products. During the same period, the Company's investment in facilities for the manufacture of these products has increased from approximately $65,000,000 to approximately $174,000,000.
>
> The composite, or weighted average, reduction in sales prices for these twelve groups of products from 1928, or the year of introduction, if later than 1928, up to and including 1937, has been approximately 40 per cent.

Capital Ratio.—An important industrial index is the ratio of invested capital to annual market value of production. This index, called capital ratio, is relatively high for the chemical and allied industries, as compared with all manufacturing industry.

From data published by *Chemical & Metallurgical Engineering*,[1] based on tax information released by the U. S. Treasury Department, a composite ratio has been calculated, representing returns of 7,608 manufacturers of chemical and allied products for the year 1934. This composite capital ratio is 1.24.

Based on financial reports for the fiscal year 1936, the composite capital ratio for nine chemical companies was 1.63. This ratio is far higher than that estimated for all manufacturing industry, namely, a ratio of not more than 1.0.

Capital Investment and Employment.—Employment cannot exist until adequate facilities have been provided. A worker must have a workplace, equipment, tools, and materials. Moreover, management must provide, out of earnings, savings with which to meet emergencies and the requirements of development and expansion. These facts might be termed *the capital law of employment.*

The capital investment required to provide employment in the chemical industry is substantial. For example, during the 10-year period from Dec. 31, 1927 to Dec. 31, 1937 the number of employees of the du Pont Company increased from 26,000 to 52,000; and in order to double the number of jobs it was necessary to more than double the capital investment. Thus, in this period the capital invested in operations (capital stock and surplus, less investment in General Motors Corporation common stock) increased from approximately $192,000,000 to approximately $440,000,000. The investment as of Dec. 31, 1937 was equivalent to $8,500 per employee. For chemical industry, therefore, *the capital law of employment* may be restated in the following specific form: Under prevailing conditions in a well-diversified chemical manufacturing enterprise, an average of approximately $8,500 must be invested in order to provide a job.

That this figure applies approximately to chemical industry generally is indicated by the following statement by E. M. Allen:

> Capital invested in chemical plants is of necessity very high. A special survey made showed an investment of over $913,000,000 for 111,901 employes. Of this amount, $585,000,000 was in capital assets and $328,000,000 was in working capital. This shows that the chemical industry has invested $8,156 for each worker on its payrolls, and I doubt

[1] **44,** 564 (1937).

whether any other industry requires such a large investment per employe. The rates of pay and annual income for the chemical wage earner are above those of other important industries.

Inter-commodity Competition.—The facility with which many chemical commodities may be interchanged in use is a notable characteristic of the industry. This means that a new product, a new process, or an improved product or process can have far-reaching effects. Following are examples:

Synthetic Methanol.—Synthetic methanol has displaced a large proportion of the wood methanol, especially for such chemical uses as making formaldehyde, dimethylaniline, and methyl salicylate. Not only is the synthetic methanol virtually a C. P. product, the price is much lower than the former price of any grade of refined wood methanol.

Synthetic Ammonia.—Before the development of a large-scale synthetic ammonia industry, anhydrous ammonia was sold only in cylinders, at prices as high as 30 cts. a pound. The use of anhydrous ammonia virtually was limited to the refrigeration industry. It is now sold in 25-ton tank cars at a price of about 4 cts. a pound, and during recent years, many new uses have been developed. Containing 83 per cent of nitrogen, anhydrous ammonia is the most concentrated form of fixed nitrogen ever used in fertilizer manufacture. Not only has cheap ammonia displaced to some extent other forms of nitrogen, the farmer has been encouraged to use more nitrogen.

When considered as an alkali anhydride, ammonia at 4 cts. a pound is equivalent to caustic soda at 1.7 cts. a pound. To some extent, ammonia has displaced caustic soda, especially where the ease with which ammonia can be handled and recovered is an advantage, as in the condensing side of oil refinery equipment. Dissociated, or "cracked," ammonia is a convenient source of hydrogen gas, and it is much cheaper in many instances than compressed hydrogen in cylinders, or electrolytic hydrogen from small generating units.

Refrigerants.—With the advent of the "Freon" dichlorodifluoro-methane type of refrigerants, which are nonflammable and nontoxic, other refrigerants were displaced virtually altogether from household refrigerator units and air-conditioning units. Therefore, the refrigeration and air-conditioning industry is

in a position to develop much more fully than with the older refrigerants.

Size of Plant.—In the chemical and allied industries, the average investment per establishment is estimated to be between four and five times as much as for all manufacturing industry. Moreover, the minimum capacity at which the advantages of mass production are realized is relatively high. Whenever possible, continuous or semi-continuous operation is practiced, and in many instances, an operator can handle a large equipment as easily as a small one. The cost of direct labor and supervision therefore goes down as the unit capacity of equipment goes up. Smoother operation, greater uniformity of product, and lower energy losses generally characterize the large equipment. Also, it is usually advantageous to integrate in a single establishment two or more operations, which, of course, increases the complexity and size.

Fairlie[1] points out that at most points in the East, and at many points in the West, sulphuric acid is purchasable at such prices, delivered, that the operation of a nitration plant of less than 30 tons of 60°Bé. daily capacity, or of a contact plant of less than 25 tons of H_2SO_4 daily, is not profitable. Fairlie gives a plant cost of $2,500 per daily ton of H_2SO_4, excluding contractor's profit, for chamber plants using brimstone gas, and $3,000 per daily ton for contact plants using platinum contact mass. This means that a plant of 100 tons daily capacity would cost about $300,000.

Regarding plant costs in the pulp and paper industry, Lee[2] reports the following statement from A. A. MacDiarmid, chief engineer, Price Brothers & Company, Canada:

> A reasonable capital requirement for a balanced 4-machine mill, with sufficient timber limits, in Eastern Canada, exclusive of any hydro-electric plant, but including working capital, should be about $32,000 per daily ton, whereas in the South, a mill on the same basis but including power plant can be set up for about $29,000 a ton.

This would mean an investment of $4,350,000 for a 150-ton mill in the South. In the same article, C. H. Herty is cited as estimat-

[1] "Sulphuric Acid Manufacture," p. 576, Reinhold Publishing Corporation (1936).

[2] *Chem. Met. Eng.*, **41**, 429 (1934).

ing an investment of $4,027,500 for a 150-ton mill (45,000 tons a year) to make paper from southern pines.

In the synthetic ammonia industry, a capacity of 100 tons daily would not be considered large, except for a plant using by-product hydrogen from electrolytic cells. A 100-ton plant, generating hydrogen independently, and including power plant, would cost about $200 per annual ton, or $7,200,000.

Describing a complete superphosphate fertilizer plant, Lodge[1] says that a fireproof steel and concrete plant including acid and acidulating departments and crane installation designed to handle 100,000 tons per year is estimated to cost approximately $1,100,000.

[1] *Chem. Met. Eng.*, **33**, 405 (1926).

CHAPTER II

ORGANIZATION

When the late Elbert H. Gary was chairman of the United States Steel Corporation, he is said to have remarked that it is just as easy to run "Big Steel" as to run a peanut stand. The judge referred, of course, to the importance of organization as a factor in business administration. Management's job is to see that the right kind of organization is set up and then to maintain the organization in good working order.

Organization is fundamentally the same in all kinds of industry, whether the industry is concerned with steel or peanuts; whether the industry employs thousands of people or few people. Only in complexity of detail does organization vary. Following are outlined the elements of organization, with particular emphasis on chemical industry.

Stockholders.—In order to start a business, operate it, and expand it, someone must put up the capital. The suppliers of share capital are the owners or stockholders. Although a business may be started by a family or some other small group, age and growth usually bring about a diversification of ownership. For example, on Dec. 31, 1937 the total of capital stock and surplus of E. I. du Pont de Nemours & Company was $625,382,517. There were 1,092,948 shares of debenture stock outstanding; 500,000 shares of preferred stock outstanding; and 11,065,762 shares of common stock outstanding. The holdings of the capital stock were as follows:

Common stock . . .	56,577
Debenture stock . . .	13,358
Preferred stock . .	7,857
Total	77,792

In his 1937 *Annual Report to Stockholders*, Lammot du Pont, president, said:

In this total there are a number of instances in which a stockholder holds more than one class of stock. With these duplications eliminated

your company is owned by 73,154 different stockholders. Geographically, this ownership is coextensive with our national boundaries, since the stock is held by residents of every state in the Union and all its important territorial possessions. About 2 per cent of the stock is held in foreign countries. There are now nearly one and one-half times as many stockholders as employes; the total number of the latter at the end of the year was approximately 52,000.

Of the 56,777 owners of the company's Common Stock, more than 90 per cent hold lots of 100 shares or less. The average common stockholding is less than 200 shares.

More than 30,000 of the company's stockholders, about 42 per cent of the total, are women. More than 6,000 stockholders are trustees. About 4,000 stockholders are employees of the company.

Among the larger stockholders are many insurance companies, whose beneficial ownership is divided among a great number of policyholders; a considerable number of investment trusts, educational institutions, hospitals, and charitable organizations, in the continuing revenues of which still broader groups of American citizens have an important interest, so that the above figures substantially understate the actual number of persons who have an interest in the earnings of your company.

Directors.—Responsible to the stockholders and representing them are the directors. The business and property of a company are managed and controlled by the board of directors. The board of directors may appoint committees having special powers. For instance, as of Dec. 31, 1937, the board of the du Pont Company comprised 36 directors of whom 9 comprised the Executive Committee and 10 comprised the Finance Committee.

Except for financial activities, the executive committee possesses all powers of the board of directors during times when the board of directors is not in meeting.

Officers.—Responsible to the board of directors or to committees thereof, are the executive officers, comprising the president, vice-presidents, treasurer, and secretary.

The activities of these officers vary according to the size, scope, and policies of the organization. In a small company, the president, more likely than not, is in effect the sole executive officer. He is versed in the detail of production, sales, research, finance, and accounting. He designs machinery, calls on customers, dabbles in the laboratory, negotiates loans, makes cost estimates. Moreover, he attends conventions, interviews the press, adjusts grievances, writes advertising copy, and executes

reports required by state and federal agencies. He may employ 100 people; if so, he is in touch almost daily with all of them.

In a larger corporation, the president shares authority and responsibility with a small group of officers. Thus, there might be a vice-president in charge of production; one in charge of sales; one in charge of finance and accounting; and, possibly, one in charge of research, development, and engineering. Except in the largest corporations, such officers are active heads of departments.

Departmental Organization.—With increasing size and diversification, the number of officers increases, and the trend is further and further toward specialization. The specialization may be functional or it may be industrial. In the du Pont Company, for instance, there are 14 functional departments, each of which serves the entire company. These are as follows:

Advertising (Advertising campaigns; preparation of copy; coordination with advertising agency; printing; coordination with sales divisions).

Development (Economic studies and analysis of processes, patents, and businesses; negotiations; management of properties).

Economist's (Compilation, analysis, and interpretation of economic data; forecasts of business conditions).

Engineering (Design; construction; industrial engineering; research; maintenance; manufacture).

Foreign Relations (Foreign service offices; information service; management of investments abroad).

Legal (Patents; general legal; taxation; trade-marks; real estate).

Office Buildings (Administration and maintenance of headquarters office buildings).

Public Relations (Press contacts; information service; preparation of publicity).

Purchasing (Market studies; commodity studies; price studies; purchasing).

Research (General research).

Service (Industrial relations; personnel; medical; safety and fire protection; real estate; communications; salvage).

Trade Analysis (Trade records; market studies).

Traffic (Procurement of transportation; rate studies; plant location studies; studies of containers and packages; handling claims).

Treasurer's (Accounting; finance; stockholders' relations; credits and collections, auditing; financial reports).

In addition to these functional departments, there are 9 industrial departments, as follows:

Ammonia (Synthetic ammonia, synthetic alcohols, and derivatives thereof).

Explosives (Dynamites; black powder; smokeless powder).

Fabrics & Finishes (Pyroxylin-coated and rubber-coated textiles; paints, varnishes, lacquers, enamels).

Krebs Pigments (Lithopone and titanium dioxide white pigments; dry colors).

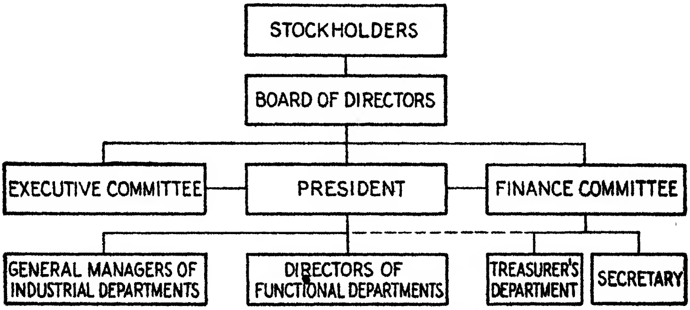

Fig. 1.—Administrative organization.

Organic Chemicals (Dyestuffs, intermediates, and other synthetic organic chemicals).

Plastics (Nitrocellulose, cellulose acetate, methacrylic and other types of plastics; fabricated articles).

Grasselli Chemicals (Acids, heavy chemicals; wood-preserving chemicals; insecticides).

R. & H. Chemicals (Chlorinated hydrocarbons; cyanides; sodium metal; peroxides; ceramic chemicals; formaldehyde).

Rayon (Viscose rayon; acetate rayon; "Cellophane" cellulose film).

Each functional department is headed by a department director and each industrial department is headed by a general manager. As indicated by the administrative organization chart, Fig. 1, the general managers and department directors report to the president. Actually, a great portion of the administrative burden is delegated by the president to the vice-presidents. Thus, one of the vice-presidents is in charge of advertising, public relations, and sales.

In some companies, the industrial departments are organized as subsidiary corporations, in which case the parent company becomes essentially a holding company. Although much can be said for the holding-company scheme of organization, existing tax laws are unfavorable to it.

Functional Organization.—Each industrial department has its own production, sales, and research divisions. Centralization of such functions is increasingly difficult as size and diversity increase. Long experience shows that a compromise between centralization and decentralization yields the best results. For example, in the du Pont Company there are 80 manufacturing plants in 27 states. The nature of the operations varies from the manufacture of wooden boxes and wood flour in Maine, the

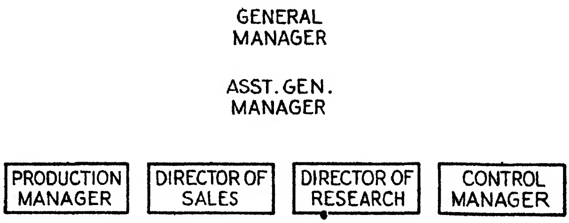

Fig. 2.—Industrial department organization.

manufacture of dyestuffs and synthetic rubber in New Jersey, the manufacture of sulphuric acid and alum in Ohio, to the manufacture of dynamite in Colorado. Obviously, one production manager could not properly supervise the operations of 80 plants in 27 states, making a large variety of products. Similarly, the scope of sales and research is altogether too broad for one man to supervise. Consequently, a compromise is effected between a purely functional type of organization and one that is purely a line type of organization. A typical industrial department organization is shown in Fig. 2.

In this organization, it will be noted that each general manager has complete authority and responsibility for sales, research, accounting, and production *within his department.* However, his advertising, legal, engineering, and other functional services are provided largely by the respective general functional departments which serve the entire company. The division of work, however, is not carried to extremes. For instance, one of the plants has a chief engineer and a dozen or so staff engineers engaged in design,

experiment, maintenance, and construction. The local engineering staff coordinates with the functional engineering department and conforms with the practices specified for the entire company. Moreover, any major project of design or construction is handled by the functional department.

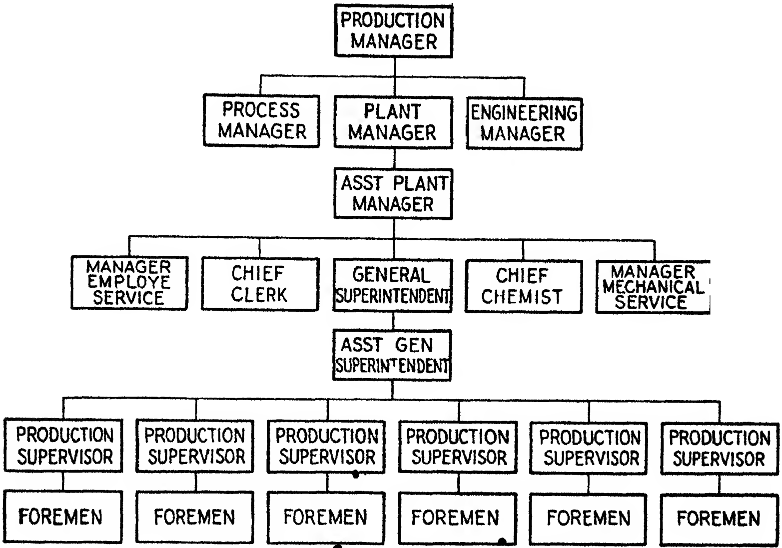

FIG. 3.—Production division organization.

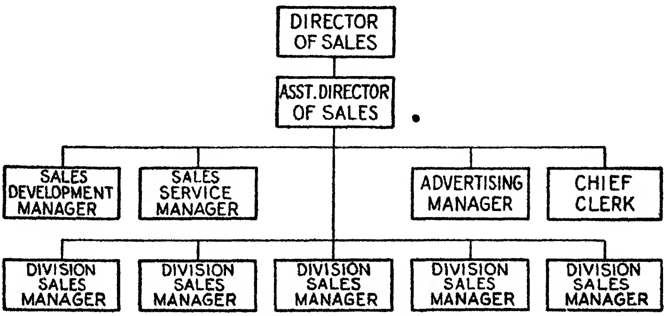

FIG. 4.—Sales division organization.

Typical organization charts for production, sales, and research are shown in Figs. 3, 4, and 5.

The functions outlined for research and sales are relatively simple and need no elaboration. Production functions, however, are complex, especially in a large plant. Therefore, the responsi-

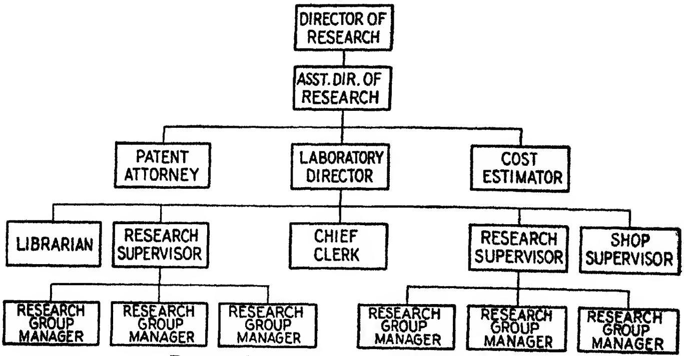

FIG. 5.—Research division organization.

bilities of the three principal production division sections comprising an existing production department are described in detail:

Process Manager's Section:

1. Compiles technical data on all processes.
2. Makes tests on plant operations.
3. Makes operating cost estimates on new processes.
4. Develops information to determine standard conditions for operating processes.
5. Prepares such technical reports as are necessary.
6. Assists in solving operating difficulties.
7. Assists in starting new equipment.
8. Has joint responsibility for changes in operating equipment and processes.
9. Edits operating manual.

Plant Manager's Section:

1. Operates all production equipment in accordance with standard procedure.
2. Maintains all production equipment.
3. Maintains all instruments.
4. Starts up all new production equipment.
5. Assumes responsibility for quantity and quality of product.
6. Compiles records for operating costs.
7. Prepares all operating reports.
8. Maintains storeroom.
9. Gives operating assistance to other departments when making tests.
10. Has joint responsibility for changes in operating equipment and processes.

Engineering Manager's Section:

1. Makes improvements in design of equipment.
2. Makes mechanical tests.
3. Makes contact with the company's central engineering design division
4. Prepares construction projects.
5. Prepares construction orders.
6. Makes preliminary drawings and sketches.
7. Makes preliminary estimates on construction costs when necessary.
8. Assists in starting new equipment.
9. Follows details of new construction to insure correct installations.
10. Has joint responsibility for changes in operating equipment and processes.

In no sense does the foregoing detail represent a standard practice. It represents an ideal. To the extent that coordination is secured among the three groups, can the ideal be approached. A production manager is therefore provided, and it is his job to effect an efficient and harmonious operation. As the late Arthur D. Little once remarked, "There is danger in an organization chart, lest it be mistaken for an organization."

CHAPTER III

RESEARCH AND DEVELOPMENT

Research is firmly established as an essential activity of successful industry. No longer is there a question whether research should be done, nor is there a question as to how research should be done. The techniques are well established. The real question is one of choice: What lines of research, what specific projects should be developed? In dealing with this question, a management can explore the following possibilities:

1. *New Uses for Present Products.*—For example, an organization making synthetic ammonia, primarily for conversion to nitric acid and other chemical plant use, found that ammonia was an excellent antichlor for water purification.

2. *New Products from Present Materials and Techniques.*—For example, an organization making synthetic ammonia and by-product carbon dioxide developed processes for making ammonium carbonates and urea from these materials. Furthermore, the technique by which synthetic ammonia was made was applied in synthesizing such alcohols as methanol, normal propanol, and isobutanol.

3. *Demands for a Specific Product or Service.*—For example, a manufacturer of mechanical household refrigerators desired a refrigerant that was nontoxic, nonflammable, and that could be used at reasonably low pressures. In response to that demand, the dichloro-difluoro-methane type of compounds was developed.

4. *Latent or Generally Unrecognized Needs.*—For example, the public did not demand air conditioning until air conditioning was available. The latent demand, however, was perceived by engineers and was finally exploited on a large scale.

5. *Suggestions, Ideas, and Inventions Originating Outside the Organization.*—Thus, a company desiring to enter a field of manufacture might do so by acquiring rights to use processes developed outside the company. The company would then be enabled to begin commercial operations with relatively little delay and could at the same time establish a research program.

6. *Savings through Improvement of Present Products and Processes.*—For example, the sulphuric acid industry in the United States is about 150 years old. Yet, improvements in process continue to be developed.

7. *Development of Radically New Techniques.*—Much cheaper strong sulphuric acid was made possible when the contact process was developed. Previously, the strong acid was made by concentrating the relatively weak chamber acid.

8. *Development of New Raw Materials.*—As long as nitric acid was made from nitrate of soda and sulphuric acid, the cost depended not only on the cost of the two raw materials, but upon the credit from by-product niter cake. One could not reliably forecast the cost of nitric acid. When the ammonia oxidation technique was developed, the economic position of nitric acid was entirely changed. Neither nitrate of soda, sulphuric acid, nor niter cake entered into the new process. Only the cost of ammonia need be considered, and this has proved to be a relatively low and gradually declining cost.

9. *Fundamental Research.*—Research undertaken with no immediate practical objective may be termed "fundamental research." Thus, a company engaged in manufacturing derivatives of cellulose might study the structure of cellulose. The objective of such a study would be purely theoretical. Years might elapse before the attainment of any significant results.

Should the research be undertaken in order to discover new derivatives of cellulose, with the hope that these might exhibit useful properties in relation to the company's existing business, then there would be a practical objective. Such research may be termed "pioneering applied research." Thus, the distinction between fundamental research and pioneering applied research is based principally upon the scope of the work and the extent to which it is limited by recognized practical objectives.

Invariably, however, fundamental research has practical significance. When, in 1869, Mendelejeff postulated a periodic classification of the elements, the mechanical household refrigerator did not exist. But more than half a century later, Midgley and his associates found Mendelejeff's table highly useful in developing the dichloro-difluoro-methane type of refrigerants.

Time Factor in Research.—Once embarked on a research project, it is important to achieve a satisfactory conclusion

expeditiously. Following are some of the reasons why delays expose a project to dangers:

1. A research project requires an expenditure for services, materials, and apparatus which may amount eventually to large sums. This expenditure, regardless of the accounting procedure by which it is charged off, may be regarded as an investment which can yield no return until the process is operating commercially. Moreover, the investment in research is increased by compound interest until it is charged off.

2. Delays result in an excessive research expense. The work on a project should proceed as continuously as possible. Shifts of personnel from one project to another are costly, since the momentum of the job is lost each time a shift is made.

3. Delays result in loss of efficiency owing to a waning enthusiasm of the personnel.

4. Delays increase the risk that the results may be anticipated by others, thereby causing possible loss of patent protection; loss of profits accruing from the initial exploitation of a new product or process; and loss of the prestige which attaches to a pioneer achievement.

5. Delays require that the organization continue to expend money on old plants until new plants can be built to benefit from the results of the research.

6. Delays postpone the time when a profit can be realized from the sale of new or improved products or from reduced operating costs.

The scale on which industrial research is carried out in this country is indicated by *Bulletin* 91 of the National Research Council, which shows that as of Jan. 1, 1933, there were 1,561 industrial research laboratories with a personnel of 23,742 technical staff. The totals as of Jan. 1, 1938 probably were about 2,000 laboratories and 40,000 technical staff. In addition, many laboratories in the government services and in universities are engaged in applied science research. In view of this large number of research agencies, among which there is tremendous competitive effort, it is not surprising that the time factor is important.

Research Costs.—The essential "raw material" for the research function is cash, and the finished product comprises commercially valuable products and processes. This product of research is unique in that there is no conceivable overproduction

so long as capital ("venture money") can be obtained. On the other hand, an underproduction in research has serious consequences. The rest of industry and the rest of the world move ahead, leaving the research laggard to be engulfed by competition.

Several yardsticks for research expense can be cited. For instance, in a company that employs several hundred technically trained persons in the various research divisions, the average cost is about $7,000 a man-year. In that same company, the ratio of research expense to sales is 2.5 per cent, a ratio that has been virtually constant during the years 1933 to 1937.

In another company, whose business is much the same and whose dollar volume of sales is only one-tenth as much, the ratio of research expense to sales is approximately 3 per cent.

These figures are useful only to indicate the average expense that might apply to a fairly large and well-established organization. For instance, in a new business, the ratio of research expense to sales might be as much as 5 per cent, 10 per cent, or more. On the other hand, in an old, long-established business, the ratio might be considerably lower than 2.5 per cent. Similarly, the average expense per man will vary considerably, depending upon the nature of the work. The figure of $7,000 a man-year comprises an average salary of $3,500 and an overhead expense of $3,500 or 100 per cent of salary. Included in the overhead expense are the following principal items: rent, heat, and light; apparatus, services, and supplies; clerical and stenographic expense; supervision; travel; and employee benefits, including social security tax.

SOME EFFECTS OF RESEARCH

New Products.—Through research, products can be created having properties not inherent in natural products. The chloroprene rubber known as neoprene is an example. Unlike natural rubber in chemical composition, neoprene is an entirely new engineering material that fits into no existing classification. It looks like rubber, acts like rubber, serves where rubber serves, and for innumerable uses it will outlast rubber many times. The basic raw materials from which it is made are coal, limestone, and salt, of which this country possesses virtually unlimited supplies. Research that led the du Pont Company to neoprene began in 1926. Almost six years of intensive work preceded the initial

manufacture on a small scale at Deepwater Point, N. J., and until the end of the year 1937, neoprene was produced at costs considerably in excess of the selling price, which was first $1.05 per pound, then $1.00, and then 75 cts. as volume was progressively increased. More than 200 manufacturers, including virtually all of the principal producers of rubber goods, used neoprene in 1937, mainly for purposes that rubber itself could not serve satisfactorily, if at all.

Improved Products.—Research may serve the public as importantly by improving an existing product as by discovering a new one. A striking example of this fact is found in "Cellophane" cellulose film. When introduced in America by the du Pont Company in 1924, through the purchase of the French patent rights, "Cellophane" was a product with a limited field and many faults. However, when ways were found to render "Cellophane" moistureproof, to strengthen it, and otherwise to adapt it to the needs of the consumer trade, the new transparent wrapping material became a factor of first rank in packaging. It inspired betterment of all wrapping materials, regardless of what variety, and, significantly, more than paid its way by reducing spoilage and handling losses in many types of goods. The price history of "Cellophane" is one of 18 successive reductions from $2.65 a pound in 1924 to an average of about 41 cts. a pound in 1936. This was increased by half a cent in 1937. Since moistureproofing was introduced in 1927, production has increased nearly fiftyfold.

Creation of New Jobs.—Successful industrial research undoubtedly creates new jobs. For example, the du Pont Company found that twelve of the company's more important developmental lines, which in 1937 accounted for 40 per cent of the sales volume, required 18,000 workers, whereas 10 years previously the same group of products provided employment for only 10,700 workers.

In a statement before the Special Senate Committee to Investigate Unemployment, Jan. 10, 1938, Lammot du Pont, president of the company, said:

> It is my carefully considered opinion that research efforts such as those I have outlined (high-pressure synthesis, chloroprene rubber synthesis, "Cellophane" development) are due more credit for the gain in jobs than any other one contributing factor. . . . We can be prosper-

ous only by serving better the diversified industries of America which use our products. We can hope to make a return on our investment only by continually developing new things for better living, which will on the one hand utilize the raw materials from farms, forests, and mines, and will on the other hand help other industries to employ more people and contribute to a higher economic development.

On many occasions, technological change has been blamed for unemployment and other current economic and social maladies. A survey made by the Machinery and Allied Products Institute[1] throws light on this subject, as indicated by the following statements quoted from the survey:

The net result of technological advancement is a great increase in employment and attainment of a higher standard of living through the efficient production and distribution of goods and services.

There was a gain of 20,000,000 new jobs during the period of most intensive technological advancement, 1900 to 1930. For each 1,000 of the 47 million added population, 422 new jobs were created in this period of twentieth century development.

If unemployment were due to machines displacing men it should be most severe in the industries where machines are used most. However, it is nearest normal levels in the most highly mechanized industries, such as automobile and textile manufacturing. . . . Most of today's unemployment is in occupations in which machines are used least. It is severest in building construction, the service trades, foundry and machine shops and heavy machinery manufacturing where most of the work is done by skilled men.

One of each seven factory workers today has a job making some product that was unknown to his grandfather fifty years ago. Eighteen of the major manufacturing industries of today have been wholly developed since 1880, and they would not be in existence except for technological advancement which has taken place since that time. They are responsible for the employment of 1,000,000 workers in manufacturing alone. It is impossible to determine accurately the additional millions who receive employment producing and processing raw materials for these industries, and handling, servicing and selling the finished products, but it may be conservatively estimated that one out of every four persons gainfully employed today owes his job to one of these eighteen new industries.

Between 1920 and 1930 the nineteen principal growing occupations gained three times as many workers as the nineteen principal vanishing

[1] "Ten Facts on Technology and Employment," February, 1936.

occupations lost. . . . The total loss in the nineteen declining occupations was about 800,000, as contrasted with a gain of more than two and a quarter million in the nineteen growing occupations.

Foreign National Control.—Whereas the largest market for camphor is the United States, the natural culture virtually is a monopoly, and until comparatively recently the foreign industry fixed prices according to its own dictates. In 1918, at a time when the price of imported camphor was as high as $3.75 a pound, the du Pont Company was encouraged to develop synthetic camphor. Although this process had certain imperfections, it might have been operated, except for an abrupt reduction in selling price from $1.36 in 1920 to 59 cts. in 1921. Presumably, in order further to discourage the latent camphor synthesis, the price was kept within reason, and finally in 1932 it reached a low of 28½ cts. Meanwhile, further developments were made in synthetic camphor, and the du Pont Company built a plant at Deepwater, N. J. which was started up early in 1934 and has operated successfully ever since. The plant now produces a large proportion of American consumption and competes with imported synthetic camphor, as well as with natural camphor.

The du Pont synthetic camphor is made from turpentine, which is available abundantly within our borders. The quality is definitely superior to the crude natural camphor and is manufactured in the U. S. P. grade as well as the technical grade. Thus, the camphor synthesis has led to the following tangible results: Freedom from foreign national control has been secured; a product of superior quality has been developed; a domestic industry, utilizing domestic raw materials, has been created; and reasonably low prices prevail.

Nitrate of soda (Chile saltpeter) was long the chief source of nitrogen for important nitrogen compounds. These materials are used in dyestuffs, fertilizers, in commercial high explosives, and in propellent powders for military and sporting use. As a result of the German blockade during the war, Chile saltpeter could not be gotten into Germany; there was, therefore, an imperative demand for another source of nitrogen. The researches of Fritz Haber and others enabled Germany to fix nitrogen from the air and convert it into military explosives and propellants. The developments since then in the ammonia synthesis and ammonia

oxidation, in the United States and other leading nations have been so important that the foreign nitrate control has been broken, and prices of important nitrogen products are on the average half of the prewar prices.

Synthetic versus Natural Products.—In 1896, a million and a half acres in Europe was devoted to the cultivation of the indigo plant. Indigo sold for about $1.25 a pound, and its cultivation required vast areas of valuable agricultural land. Then the synthetic indigo industry was developed from the classical researches of Baeyer. His synthetic indigo sold for about one-third the cost of the natural product. At the same time, about a half million acres in Europe and Western Asia was under cultivation for the madder root. This material was the source of the dye alizarin, which cost about $10.00 a pound. Through the researches begun by Perkin in England, the so-called aniline dyes have displaced the agricultural production of coloring matters. Alizarin now sells at one-twentieth of the cost of making it from the madder root. Synthetic dyes are better, cheaper, and vastly more diversified than those from agriculture.

Conservation of Natural Resources.—Undoubtedly, an abundance of natural resources is not conducive to careful conservation. Nevertheless, the United States, with its reputation for profligacy, has taken a leading part in conservational research. For example, the yield of gasoline has increased from 6 gal. per barrel (42 gal.) of crude oil during the World War to 19 gal. per barrel in 1937. Moreover, the proved potential yield is 46 gal. of gasoline per 42-gal. barrel of crude.[1] By the recently developed polymerization process, it is feasible to produce high-grade oils from refinery gases. Moreover, the yield of crude oil itself has been improved by opening the oil-bearing rock through such methods as acidulation and the use of high explosives.

The utilization of coal has been enormously improved through such developments as by-product coking, improved furnace design, and higher operating pressures in steam plants. The developments in hydrogenation, originating in Germany, have provided a vast potential supply of liquid hydrocarbons from coal.

Forest resources, once on the way toward virtual extinction, are now in no danger. Chemical treatments greatly prolong the

[1] *Chem. Met. Eng.*, **44**, 547 (1937).

life of lumber against destruction by rot, fungi, and insects. Flameproofing of wood is practiced successfully. The large-scale destructive distillation of hard woods, in order to obtain such chemicals as methanol, acetic acid, and acetone, is no longer a necessity. The shift of the paper pulp industry toward the South is already taking place. Research has pointed the way not only toward improved pulping processes, but toward the replacement of the timber itself.

Decreased Costs of Production.—Central-station power generation has been established so long that one might expect but little progress in recent years. On the contrary, tremendous progress has been made.

In 1919, the average coal consumption in central-station generating plants was 3.2 lb. per kilowatt-hour. Ten years later, in 1929, the average coal consumption had been reduced to 1.65 lb. per kilowatt-hour. The gain in economy calculated on the 1929 power production is approximately $100,000,000 a year. Stated in other terms, the output of electricity per ton of coal was doubled in 10 years. Since 1929, still further progress has been made. Not only does the consumer benefit through lower rates; the country benefits, because the coal resources are conserved.

What was behind such improved economy? As late as 1921, the properties of steam were known to pressures of only 200 lb.; this limitation of knowledge concerning steam in turn limited the design of engines. By 1925 the properties were known at pressures as high as 1,200 lb., and in the following year engines were built and operated successfully using steam at that pressure. The resulting economy was so great that high-pressure steam is used universally in large power plants. Other factors have contributed to increased economy, such as better boilers and better generators; however, the basic element in the progress was research on the properties of steam.

The increased economy of coal consumption in cement manufacture is cited by Tryon and Rogers[1] and continued by N. Yaworski. Thus, in 1914 about 220 lb. of coal was consumed per barrel of cement, whereas in 1934 the consumption had decreased to about 145 lb. per barrel. Assuming coal at $4 per ton, the saving in coal would amount to 15 cts. per barrel of cement.

[1] "Statistical Studies of Progress in Fuel Efficiency," *Trans. Second World Power Conference*, **6**, 244, Berlin (1930).

PROCESS DEVELOPMENT

Between the discoveries of the research laboratory and the realization of commercial operation lies the field of process development. Neglect to recognize economic factors in technical development work is such a common cause of failure that there is little danger of being too conservative when considering the commercial possibilities of new processes. Although this discussion contains much that is repetition, research and operating men alike should continually be impressed with the necessity of sound, step-by-step progress from the first laboratory experiment to ultimate factory production.

Research and Development Contrasted.—As pointed out by Mees[1] the work of the development department is an extension of laboratory research. The development of commercial processes calls for different personal characteristics than those needed for laboratory research; consequently, it is usually carried on by a separate staff if the size of the laboratory permits. Since there must be coordination between the two, general supervision should be unified. Mees says:

> The commonest mistake is to transfer laboratory work to the manufacturing department too soon; experimenting in a manufacturing department is a costly matter, and the experimental work should be done on a small scale under control of the laboratory before any attempt is made to transfer it to a full-scale manufacturing department.
>
> The development department itself should have an organization separate from the research laboratory, though under the same general direction. It will study all proposals for new methods, processes or products which may be submitted to the company, and will report on them, these reports bearing at their conclusion definite recommendations on which the executives of the company can act.

Importance of Intermediate Experimentation.—Chemical engineers agree generally that only in a few exceptional cases is the direct transfer of a process from laboratory to plant permissible. Cooper[2] has summarized a symposium on factory experimental procedure contributed by technologists in widely varying industries:

[1] "Organization of Industrial Scientific Research," McGraw-Hill Book Company, Inc., New York (1920).

[2] *Chem. Met. Eng.*, **32**, 426 (1925).

Direct transfer is a hazardous undertaking and is disliked by the ordinary chemical engineer. Risk is lessened by extending the period of preliminary study. If it were possible to anticipate every variable that will be involved, there would be little to fear, but the average engineer prefers to admit the possibility of overlooking something and likes to proceed cautiously. An example was cited where every variable in the extraction of a vegetable oil was supposed to be known, and a 3-ton extractor was ordered, but the operation worked differently on a large scale. A filter press should have been used to remove much of the oil. The difficulties of operating on a large scale are sometimes less than those encountered in the laboratory, but more often they are much greater.

Except in the most elementary examples, the process should at least go from the laboratory to a unit plant, including the largest single piece of apparatus that is to be used. This plan has the merit of giving actual factory production at once, though not on the full ultimate scale. If standard equipment is employed, the unit plant will not cost much more than an intermediate plant and will make a strong appeal to the confident promoter.

One company spent $15,000 on a small-scale plant and found out that the process was not profitable, thus saving most of the $100,000, the estimated cost of the full-sized equipment. If a maximum of caution is desired, a combination of semi-factory scale equipment and unit plant should be employed, especially when profit is more important than speed, and competition is keen. When a well-known oil refining process was being installed, the deposition of carbon was overlooked or overestimated, even in the intermediate study; but the full-sized unit brought it out. The Standard Oil Company of Indiana, in developing the Burton process, had to prepare for more than a threefold increase of pressure. They started with a 1-qt. bomb and the stills were increased from 13 to 50 gal. and then to a unit plant of 8,500 gal. costing $100,000. This was later multiplied into a battery according to requirements.

Whiting's Concept of Process Development.—Although it was published in 1912, one of the clearest expositions of chemical development is that by Whiting.[1] He divides process evolution into five distinct stages:

1. Beaker or laboratory stage.
2. Small-sized model.
3. Large-sized unit.

[1] "The Commercial Development of Chemical Processes," Eighth International Congress of Applied Chemistry, New York (1912).

4. Semicommercial plant.
5. Commercial plant.

Beaker or Laboratory Stage.—The function of the first stage is to test the correctness of the technical principle of the process, the novelty, and the commercial soundness.

Common sense dictates such a preliminary investigation as a safeguard against wastage of money and effort. Quoting Whiting:

> The first step in this direction is to conduct such experiments as may be necessary for a full preliminary study of the technical side of the problem in hand. It is not the function of the laboratory to produce accurately the condition of practical work, but rather to enable the experimenter to test out the fundamental principles on a small scale with a correspondingly small outlay of time and money. The aim should be, therefore, to isolate the idea, to divorce it from any conditions which may be misleading in their effect, and also to subject it to severe strains to determine its pluck and endurance. Moreover, the experiments should include a study of the underlying causes of the defects in existing competing processes, and their extent and importance. This study of the technical side of the problem is necessary as an insurance against useless work.
>
> But the function of the first stage is not ended here. The novelty of the process must likewise be investigated by a thorough study of the state of the art in textbooks, periodicals and patent office records, an undertaking which requires time and patience and not a little self-control. In the investigations of the Whiting cell, more than a thousand references were found, classified, and catalogued. And just as important as the search covering the novelty of the process is a study to determine whether the basic commercial conditions surrounding this process are sound, that is, whether the raw materials required are to be obtained at a reasonable price and in sufficient quantities; whether the operation is likely to involve any extra-hazardous conditions, and whether there is a permanent market of sufficient size and stability for the product. From a practical standpoint it is useless to spend time and money on a process not commercially sound, but this is being done constantly by inventors all over the world. I have personally known of several cases where men have spent years developing a secret process, only to find in the end that the market conditions were unsound, a fact easily ascertainable in the beginning.

Small-sized Model.—Assuming that the laboratory stage yields favorable results, development passes to the small-sized

model, the purpose of which is to determine the optimum operating conditions. In order to facilitate the study of each variable, the design of the model should be as simple as possible, and flexible enough to meet the wide range of conditions that should be investigated in a preliminary way. Again quoting Whiting:

The model should be as flexible as possible. For instance, in the original design of the model of the Whiting cell, the compartments in which the salt is decomposed and the amalgam oxidized were made independent of one another, and in such a way that the dimensions of each and the relationship of one to another could be varied independently within wide limits. By this means, with a single model, we were able to determine the proper size and shape of each compartment, their relationship and the most effective method of operation. It is interesting to note that in this instance the results obtained with the first model have had permanent value. This is not always true. By operating the apparatus under a great variety of conditions, the best procedure can be ascertained and the scope of the invention determined within the limits of the experiments performed.

The small-sized model, moreover, should be big enough to permit the manufacture of a sufficient quantity of the product to enable the experimenter to determine its quality. In the laboratory one experiments generally with pure chemicals. In the small model it is well to use commercial materials, the impurities in which often are disturbing factors in the success of the process. As regards the final efficiency of the process under actual conditions of plant operation, very little of value can be learned from this model, but much knowledge may be obtained which will aid in the design of the final apparatus and in determining the choice of materials to be used therein.

Large-sized Unit.—The effects of the operating variables having been determined, the elementary design should be worked out. To do this is the function of the large-sized unit. At this stage a broad knowledge of engineering materials and of other practical aspects of design is especially helpful. That is one of the reasons for the rapid progress characteristic of large technical organizations, in which each major problem of design is assigned to a specialist.

With increased size, the optimum operating conditions as determined for the small-sized model may not hold. Consequently, flexibility in design remains desirable in the large-sized unit. According to Whiting, this is the most critical stage in the entire development program:

The tendency to hurry over the third stage in the evolution of a process is often almost overpowering. After a few weeks or a few months, as the case may be, the operation of so small a plant becomes tedious, and the inventor is apt to chafe at not being able to make more rapid progress. It is evident, however, that defects are much more easily remedied on a single unit than on a great number of units, and the more perfect a process emerges from this stage, the shorter and easier will be the subsequent stages, and more complete the success. Moreover, many chemical processes which work well on a small scale are failures on a large scale. Thus, in the development of the (Whiting) electrolytic cell, the provision made for decomposing the amalgam in the oxidizing compartment, though perfectly satisfactory when applied to the small-sized model, proved inefficient and unreliable in the life-sized unit, necessitating much research work and a redesign of the apparatus before the defect was overcome. Likewise, many processes have defects that may be called accumulative. I have known a piece of apparatus to work well for a period of 7 months, and at the end of that time develop a defect which made it practically useless.

Semicommercial Plant.—At the termination of the third stage, operating conditions and the elements of design will have been determined, and the next step—the semicommercial plant—has for a purpose the determination of efficiency, simulating in design and operating conditions the final plant in every respect except capacity. Compared with previous stages, experimental work of this sort requires a generous financial backing, and this brings up the problem of financing the enterprise prior to commercial production. Whiting says:

At the beginning of this stage it is necessary to consider a new and very necessary element for success—money. The first three stages consume large amounts of time and energy, but comparatively little hard cash. Now, however, a considerable sum will be needed to carry the process through the fourth stage. Of course, there are many ways of proceeding to get this money, and conditions must govern the final analysis, but I would suggest that there are advantages in the erection of this semi-commercial plant in connection with some going concern, giving certain limited rights to use the process, if successful, in consideration of the opportunities and equipment furnished. Generally this is a safer and more economical arrangement at this stage than to attempt to form a company for the exploitation of the process and the erection of a small independent plant. The well-oiled machinery of the allied concern, its purchasing department, its engineers, its laboratory and work-

men will all be available for the new work, leaving the experimenter free to concentrate on his own special problems.

The proper size of this plant depends, of course, upon individual conditions. It should be as small as possible, and still be able to produce enough of its product to permit the testing of its quality under the conditions of actual use. It should be large enough to indicate something of the cost and quality of the labor required for the commercial operation of the process. The life-sized unit was looked after by skilled men. It is now necessary to prove that the process may be operated by ordinary cheap labor. Moreover, the plant should contain a sufficient number of units to enable the experimenter to determine their efficiency under the average conditions of plant operation. A single unit may do very good work when petted and pampered by constant adjustments, but give it its place in a series of units all subject to the grueling test of average conditions and it often falls down. Much can be learned from this little plant, especially as regards the general arrangement of the large plant and the relation of one piece of apparatus to another. These are important points, which affect not only the first cost of building the final plant, but also the cost of its operation over an extended period of time, and both factors will aid greatly in obtaining the full measure of benefits to be derived from the development work.

Commercial Plant.—If the process survives the exacting tests of semicommercial operation, and estimates indicate that the production cost will be sufficiently low, the last and final stage of development, the full-sized commercial plant, may be designed with the assurance that all risks, both technical and economic, have been minimized.

Lewis and Radasch[1] recommend a procedure for process development similar to Whiting's and with particular reference to stoichiometric methods of calculating plant-scale capacities and requirements, based on laboratory or small-scale data.

AN EXAMPLE OF PROCESS DEVELOPMENT

In the viscose rayon process, sodium sulphate is produced as a waste product, and the electrolysis of this sodium sulphate to regenerate caustic soda and sulphuric acid has been suggested. The commercial feasibility of such a process will be considered, assuming that sufficient sodium sulphate is available to supply a plant of economic size.

[1] "Industrial Stoichiometry," McGraw-Hill Book Company, Inc., New York (1926).

Marketing is not a factor in this example, as the entire output of acid and alkali would be consumed as made. It is required that the caustic soda be delivered as a 20 per cent solution or stronger, and nearly free from sodium sulphate; and that the sulphuric acid concentration be at least 8 per cent, containing not more than 18 per cent of sodium sulphate.

Chemistry of the Process.—It was found that sodium sulphate solution could be electrolyzed in a diaphragm cell having a platinum anode and an iron cathode; the runs being made on a small elementary cell. The following data, essential to subsequent experiments, were then secured:

1. Electrical conductance of sodium sulphate solutions of concentrations of 6 to 30 per cent and temperatures of 40° to 90°C.
2. Specific gravity of sodium sulphate solutions of concentrations of 6 to 30 per cent and temperatures of 40° to 90°C.
3. Solubility of sodium sulphate in caustic soda solutions.
4. Solubility of sodium sulphate in sulphuric acid solutions.

Small-scale Laboratory Operation.—The foregoing fundamental data having been obtained, several runs were made on a small-sized laboratory cell, the effective electrode dimensions of which were 5×8 in. The cell was 2.5 in. between electrodes, was open at the top, and had a Duriron anode. The diaphragms were of ordinary cotton-filled asbestos paper. With this cell, the following factors were established:

1. An electrolyte approaching saturation is undesirable, as some Glauber's salt will precipitate, thus obstructing the free flow of liquid through the cell and piping.
2. The current density should be not less than 50 amp. per square foot, in order to insure sufficient decomposition of the sodium sulphate. On the other hand, a current density greater than 150 amp. per square foot should be avoided, as this causes overheating and inordinately high energy loss.
3. The distance between the electrodes should be less than 2.5 in., preferably not more than 1 in., in order to obtain a sufficiently low operating voltage.
4. With prolonged operation, ordinary cotton-filled asbestos paper is unsatisfactory as an anode diaphragm, owing to partial disintegration, which causes an uneven flow of electrolyte.
5. Control analyses of the acid solution showed that the iron content is too high when a Duriron anode is used.

6. Losses, especially of the caustic solution, were caused by mist which formed at the electrodes and was dissipated in the atmosphere.

7. Due to the difference in head between the upper and lower parts of the cell, the rate of flow, and, consequently, the composition of the effluent, varied widely.

Large-scale Laboratory Operation.—Based on the experience gained from the small-sized laboratory model, another cell was constructed in order to fix more definitely the design factors.

First, however, a search was made for a suitable anode material. Various substances, including carbon, graphite, nickel, silicon, ferrosilicon, Duriron, antimonial lead, and commercial lead, were tested as an anode under conditions paralleling as nearly as possible those of cell operation. Only three materials—Duriron, antimonial lead, and commercial lead—resisted satisfactorily the severe conditions to which they were subjected. Commercial lead was the most satisfactory, as a film of firmly adherent oxide was formed, thus preventing any further loss of metal. This film, furthermore, was found to be a good conductor of electricity.

A similar investigation of various diaphragm materials was made, with the result that a nearly pure asbestos paper was selected. Thicker material, such as asbestos board, was found to have too much electrical resistance. Asbestos cloth was found to be too porous to function effectively.

With this additional information regarding anode materials and diaphragm materials, a large-sized unit was constructed in which the faults of the previous small-sized model were overcome. The decrease in distance between the electrodes from 2.5 to 0.75 in. decreased the voltage from 8.1 to 5.1 volts when the current density was 110 amp. per square foot. With continued operation, the lead anode corroded slightly. The use of pure asbestos paper as a diaphragm corrected the trouble from disintegration and leakage. By closing the top of the cell, making it wider in proportion to its height, and introducing the feed under a slight head, the flow through the upper and lower parts of the diaphragm was better equalized. Losses from misting were stopped by sheet-lead covers.

In principle, the large-sized unit resembled the Allen-Moore cell. The electrodes consisted of perforated plates, the inner surfaces of which were in close contact with the asbestos paper diaphragm. The electrodes were clamped against a thin frame of wood treated with asphalt paint, thus forming a cell. The sodium sulphate solution was fed into the cell, and the products of electrolysis, together with some undecomposed sodium sulphate, flowed continuously through the diaphragms and the perforated electrodes.

Semicommercial Unit Operation.—The next step was the construction of a third cell, which in refinement of design approached the proposed commercial apparatus. As this cell had a power consumption of about 100 amp., it was large enough to yield data upon which accurate cost estimates could be based. This cell was relatively greater in width than in height, in order to lessen still further the variation in flow between the top and the bottom of the diaphragm. With this semicommercial cell, a series of nine carefully controlled runs was made, in order to fix definitely the operating conditions and to assure that the results could be duplicated in practice.

The cathode was of perforated sheet iron and the anode was of perforated sheet lead. Ordinarily asbestos paper was used at the cathode and pure asbestos paper at the anode. The distance between the electrodes, which were unsubmerged, was 0.7 in.

Operating the cell under a liquid head of 4 to 6 in., and using a 22 per cent sodium sulphate solution preheated to 80° to 90°C., and a current density of 100 amp. per square foot, a current efficiency of 85 to 92 per cent at 4.3 volts was obtained. The yield was 0.65 lb. of caustic soda and 0.79 lb. of sulphuric acid per kilowatt-hour. The caustic soda was obtained as a 6.5 per cent solution containing 15 per cent of sodium sulphate, and the sulphuric acid was in the form of an 11 per cent solution containing about 13 per cent of sodium sulphate.

Experiments with the caustic effluent indicated that at a caustic soda concentration of 20 to 25 per cent and at a temperature of 90° to 100°C., most of the sodium sulphate can be precipitated as is done with sodium chloride in chlorine-caustic soda practice. This method of purification, however, cannot be applied to the acid liquor. Up to a certain concentration of

sulphuric acid, the solubility of sodium sulphate increases, and beyond this point considerable acid is lost by the crystallization of acid sulphates. The acid liquor, however, can be used as such or fortified with concentrated acid.

Consideration of Commercial Feasibility.—Although final conclusions should not be based on the performance of a single cell, an estimate of probable commercial performance can be made. At a current density of 115 amp. per square foot, the voltage was 4.2 to 5.0 volts; whereas in the chlorine-caustic soda cell, it is 3.5 to 4.0 volts at a current density of 75 amp. per square foot. Based on 85 per cent current efficiency and 4.3 volts, which can be obtained by lowering the current density to 100 amp. per square foot, the yield would be 0.65 lb. of caustic soda and 0.79 lb. of sulphuric acid per kilowatt-hour, which compares with a yield of 0.70 to 0.72 lb. of caustic soda per kilowatt-hour claimed for chlorine-caustic soda practice.

As the process is similar to the production of chlorine and caustic soda in the Allen-Moore cell, a step-by-step cost estimate was made as compared with Allen-Moore costs, for which actual operating figures were available. The important items of cost—namely, direct labor, electric power, and overhead—are substantially the same per pound of caustic for both processes; and the total of other items, such as steam, diaphragms, anodes, and miscellaneous supplies, also, is about the same. There is no anode cost in the sodium sulphate process, but the life of the anode diaphragm will be much shorter than in chlorine-caustic soda practice.

For the assumed conditions, the one item in favor of the sodium sulphate process is raw-material cost, as the sodium sulphate is secured for the cost of crystallization. This slight advantage, however, is more than offset by the difference in the value of the by-products. Neglecting the caustic soda common to both, the sodium sulphate process gives oxygen and dilute sulphuric acid containing sodium sulphate, as against chlorine for the salt process. Under favorable conditions, the sulphuric acid may be worth slightly more than 1 ct. per pound of caustic soda produced, whereas the chlorine is worth from 2 to 3 cts. for conversion into bleach or liquid chlorine. Unless the oxygen can be sold or used without being compressed into cylinders, it can scarcely affect the balance of about 2 cts. per pound of caustic soda in favor of the

chlorine-caustic soda process. This was so unfavorable to the process being investigated that further study did not seem justified.

FINANCING THE CHEMICAL PROJECT

Every proposed product or process involves speculative risk. Failure commonly is caused by the inability of a company to carry to completeness the necessary research and development. Even with a perfectly sound idea, the risk may be too great in proportion to the financial resources of the company. For example, if a company desired to develop a process for the low-temperature carbonization of coal, judgment would dictate that ample working capital and a large research and development staff would be needed. A problem of this sort is so complex that the talents of many men are required if a successful solution is to be reached within reasonable time. Furthermore, the experimental equipment is complex and costly. It is no safe undertaking for a company of limited resources. The cost of experimental work might run to several million dollars before a solution could be achieved. Again, a company having working capital of say $1,000,000 above ordinary needs might consider that a project for extracting potash from refractory minerals involves too much risk, whereas the same project might be highly interesting to a company having ten times as much working capital. The probability that a small company could develop such processes successfully is slight. The same would hold for a large company, if it did not have ample working capital.

On the other hand, some problems are relatively simple, and the outcome can be predicted with reasonable certainty from the start. A problem of this kind might be, for example, the development of a paint and varnish remover. On such a problem, an expenditure of several thousand dollars for research would go a long way toward obtaining conclusive results, and an expenditure of $10,000 probably would be sufficient to produce a commercially satisfactory product. All the difficulties in the development of a process or product cannot be foreseen, but from the nature of the underlying science and with the experience gained from similar problems, it is possible to forecast the development expense reasonably well.

Characteristics of the Chemical Development.—Three factors, at least, characterize the industrial chemical development:

1. The time required to develop a large-scale process is difficult to forecast and invariably is longer than forecast. In an address before the National Association of Manufacturers (New York City, Dec. 8, 1937) K. T. Compton pointed out that the lapse of time between initial research and profit is at least 10 years. In an address before the same audience, E. R. Weidlein confirmed this view when he said that about 10 years is required to develop a chemical process. These authorities referred of course to processes involving new chemistry and technology rather than improvements in existing processes.

2. The investment required is relatively large. This is partly inherent in the nature of chemical development itself and partly inherent in the minimum requirements for economical production. These factors are explained elsewhere in this book.

3. The fundamentals of chemical industry—not to mention details—are not widely understood among bankers. The industry is relatively new as an investment field. The risk inherent in new developments should, if possible, be spread over a number of existing lines of manufacture. This mode of diversification and growth is typical of chemical industry.

Deferred Profits.—A point not sufficiently appreciated is that a profit rarely is achieved coincident with the start of large-scale operation. The reasons are clear. In order to make a profit, the gross income from sales must exceed the total of operating expense and other expense. Yet the start of the factory operations is just the time when costs are likely to be highest and income from sales the lowest. Usually, a management realizes that for a period of one, two, or three years a profit is not to be expected. A price schedule is set that may be considerably below current costs, realizing also that appreciable sales volume cannot be achieved unless the price is competitive from the start. Gradually, with a rising sales volume, and with additional operating experience, costs are reduced, and this in turn ultimately permits price reductions that bear a direct relationship to costs. To add to the difficulties of initial operation, quality is rarely satisfactory or uniform, whereas successful sales introduction may depend much on quality. Still another factor relating to profits is the business cycle. A product intro-

duced during a declining or depressed part of the business cycle will not have the outlet normally forecast.

Illustrating some of the points in the foregoing discussion, the gross sales and net profits of an existing chemical business have been charted from the first 12 years of commercial operation. The business was organized as a subsidiary of an established chemical company following 7 years of experimental work, during which period substantial expenditures were made. During the first 3 years of operation, large losses resulted. In the fourth year, operations broke even. At this stage, the management decided that, if large profits were to be achieved, further extensive development was necessary. Thus, immediate profits were sacrificed deliberately, in order to improve the long-term prospects of the business. As a result, not until the seventh year of operation did the business show a profit. Beyond the seventh year, earnings increased rapidly, so that during the tenth year of operation the cumulative deficit was overcome.

After the seventh year, sales increased sharply, for the following reasons:

1. Operating and other costs were reduced to a satisfactory figure.

2. Satisfactory outlets for the original products had been established.

3. Additional research had resulted in new products having varied uses.

4. Quality of all products was steadily improved.

5. Prices of important volume products were reduced progressively and without pressure from customers.

Other points worth noting are:

1. A period of 14 years elapsed between the initial experimental work and sustained profitable operation.

2. A period of nearly 10 years elapsed between initial commercial operation and the realization of an earned surplus.

3. At the end of the tenth year, virtually all of the original plant was obsolete, and the plant investment had increased about tenfold.

4. At the end of the tenth year, the selling prices of the principal products were about half those originally forecast.

5. The markets, however, proved to be larger than forecast, and mill costs lower.

The foregoing is a typical example of the evolution of a successful chemical enterprise. Many projects never attain profitable operation and are abandoned; few projects quickly show sustained profits. As additional evidence, the du Pont Company affords several examples. Their dye business was operated for 6 years before a profit was shown. During this period, the total expenditures exceeded $40,000,000. Similarly, the synthetic ammonia and related business was operated at a loss for more than 7 years.

Methods of Financing.—Exploitation of new processes involves enough risk without adding the risk inherent in a newly organized independent company; consequently, almost every development is started either as a division, department, or subsidiary of an existing, seasoned organization. Funds for the extension of operations can be obtained in a number of ways, and the method selected will depend upon the amount of money needed, the financial condition of the company, and business conditions generally. Additional capital stock may be issued when large sums are necessary; or the company may draw upon its credit and issue long-term notes or bonds. If temporary financing only is needed, it may issue short-term notes. Financial conditions and liquidity permitting, the funds may be obtained from undistributed earnings.

Selecting the Method of Financing.—Assuming that the organization is free to choose any of the foregoing methods of financing, several factors should be considered, as follows:

1. Financing through the sale of additional *capital stock* increases the total assets and capital of the business without creating fixed charges in the bookkeeping sense. Ordinarily, such capital is obtained at a substantial cost, as represented by the underwriter's discount. On the other hand, the public sale of capital stock is a possible means of creating additional good will, and, in any event, creates wider interest in the company's affairs.

2. Financing through *long-term loans* or *bonds* creates a direct, fixed obligation senior to the capital stock. Contrast this with capital stock, which is not a form of indebtedness, and which imposes no *fixed* charges.

3. Financing new processes through *short-term loans* is not practiced extensively in the chemical industry. Generally, the

funds needed for development must be available for a long term of years.

4. Financing from undistributed earnings ordinarily is most economical and indicates prudence and financial strength. It is practiced by many of the largest chemical companies. At the time of writing, it should be noted that, owing to the provisions of federal legislation regarding taxes on undistributed earnings, this method of financing is severely penalized.

Promoting the New Company.—Should it be decided to form an independent company to exploit the process, the advice of a professional promoter is advisable. The legitimate promoter is not to be confused with the variety of stock salesman identified with "wildcat" ventures.

One of the first steps in the promotion of an enterprise will be a critical investigation by the promoter. In large part, the investigation may be a repetition of work already done, but an experienced promoter is likely to think of many questions not considered by his more optimistic clients. According to Walker,[1] an exhaustive investigation prior to the promotion should include the following subjects:

1. Magnitude and stability of the demand for the product.
2. Existing and potential competition.
3. Size, history, and profits of other companies in the same or allied fields.
4. Capital investment necessary to establish a new concern of economic size.
5. Possibility of substitute products and fluctuation in demand.
6. Possible effect of hostile legislative measures.
7. Probable cost of production.
8. Probability of obtaining efficient managers for the plant.
9. Feasibility of proposed location.

The number of successful enterprises started in this way is small. Usually, it is wiser for the new company to begin operations on some product based on seasoned methods of manufacture. Later, it can more safely embark on new ventures.

[1] "Corporation Finance," Alexander Hamilton Institute, New York.

CHAPTER IV

PROJECT ANALYSIS

Chemical engineers frequently are faced with the perplexing question whether money should be invested in a project, at the risk of considerable loss; or whether the money should be conserved, at the risk of overlooking a good bet. The course of action is determined as much as possible by facts, though sooner or later the human element must enter, when the final decision is made.

The more important projects relate to the following types of capital commitments:

1. Expansion of established lines. For instance, an eastern manufacturer of alkali products expanded by building a similar plant on the Pacific Coast.

2. Development of new lines. For instance, a manufacturer of explosives, dyes, and heavy chemicals, seeking a dependable and economical source of ammonia, invested in a synthetic ammonia process and plant.

3. Additions or improvements that will increase the return on the entire investment, bring about better working conditions, or improve quality. For instance, a manufacturer of chamber sulphuric acid substituted ammonia oxidation units for niter pots, thereby effecting substantial savings in cost.

Regardless of the nature of the project, the economic aspects must be investigated and reported to the management. The procedure by which this is accomplished is commonly called "commercial research" or "project analysis." Project analysis can be resolved into the following constituent studies:

1. Production cost.
2. Market survey.
3. Price study.
4. Capital investment.
5. Return on investment.

Production Cost.—Production cost is logically the first problem for study, since it will indicate whether further development

should be undertaken. A large proportion of wasted research effort is caused either by a complete disregard of cost estimates or by gross inaccuracies therein. The least that might be done in every instance is to assume theoretical yields and the most optimistic results generally. Then, if the proposed process fails to meet such extremely favorable conditions, it must be hopeless.

As pointed out by Becket,[1] in those instances in which cost estimates have been made, but in which the ultimate result has been failure, serious errors of omission usually can be demonstrated. Poor judgment also may be a contributing factor. Quoting Becket:

> Now, it is deserving of special emphasis that in a large proportion of the hopeless cases that have come to my attention, the great error, the cause of the wasted effort, has been found either in complete omission of any attempt to estimate the cost of manufacture, or more often to predetermine it with reasonable accuracy. In all of these cases a revealing estimate could have been made by assuming theoretical yields from the chemical reactions and excellent results in connection with all other factors. The last thought is worthy of a little elaboration in that it provides a method of precluding these extremely wasteful procedures. By assuming theoretical yields from the chemical or electrochemical reactions, which are oftentimes interestingly clever, and by further taking the most optimistic view of all other factors that an experienced, reasonably intelligent engineer would dare to assume, it has been possible by cost estimating in this way to convince many who have experimented diligently that they have been seeking a worthless goal. The saddest instances revealed by this method are those in which mental energy and capital have been wasted to a much greater extent, in which the technology of a process has been carried to successful demonstration on a minor scale and for which great economy has been forecast in the operation of a plant of commercial size. In cases of the latter class cost estimates had been prepared by the proponents. Then, wherein lies the difficulty? The most serious errors are those of complete omission of important cost factors rather than the application of poor judgment to the factors considered, although, frequently, both errors are combined.

That a stronger impression may be left of the type of pitfalls that have brought keen disappointment to many sanguine and in some cases obstinate persons, it may be well to depart from broad generalizations and mention a very few specific cases drawn from actual experience.

[1] *Chem. Met. Eng.*, **33**, 283 (1926).

For obvious reasons, the citations will avoid identification of processes or persons.

Within the past decade a process for the extraction of potash from an abundant domestic mineral was devised, considerable preliminary work was performed, the technology of the novel steps was developed in semi-commercial apparatus and the process was offered to one of the companies with which I am connected. In common with other processes of the kind the transition from potash-bearing rock to a soluble potash salt offered the major problem, the solution of which presented the chief novelty. Hence, most of the money and effort were expended on the design, development and operation of the furnace in which the rock was decomposed at a moderate temperature through ingenious reactions. Good thermal economy and a high recovery of soluble potash were attained and were accepted as criteria of commercial success. The steps subsequent to leaching of the furnaced product, which were principally washing and evaporating operations, fretted the chief technologist and his associates not at all and had never been carried out quantitatively, on the ground that they represented "perfectly simple chemical engineering." Early in our investigation an estimate was made of the cost of operating this complete process, based on the assumption that substantially theoretical yields would result from the furnace reactions, and it brought to light that the cost of evaporating the necessarily dilute solutions, even by the most efficient means, precluded the commercial success of the project, if the average selling prices of the potassium salt and the by-products were duly considered. Neglect to estimate the cost of "perfectly simple chemical engineering" processes explains the failure of this enterprise.

An example of a different class is represented by a high-temperature electrolytic process for the reduction of a metal having a melting point over 1500°C., which was offered after considerable work had been conducted on a moderate scale. Samples of the product were presented with the claims for predicted commercial success. In this instance, quite apart from glaring practical difficulties that had not been solved and speculation concerning the quality of the product, the estimated cost of the three items, raw materials, power and labor, assuming 100 per cent current (ampere-hour) efficiency and a large-scale operation, slightly exceeded the highest selling price of the product over the several years preceding. The market price of this product is today 40 per cent less than at the time of the investigation. Later, this process met with a reception enthusiastic enough to be optioned by another group who continued experimentation for a few months, but it was soon thereafter abandoned.

Before attempting to predetermine costs, it is a logical procedure to select an appropriate scale of operation and then to visualize the com-

plete plant and organization required for the desired end. However clearly a process may have been conceived as a succession of chemical reactions and unit processes, cost estimating each material and operation develops a clearer picture of the producing and economic structures; and the mental courage requisite to develop a thorough cost estimate will find its reward in an enhanced understanding of the project. In every case the estimate deserves careful analysis. An estimate which reflects favorably on the process will show points of strength and of relative weakness, so that further work can be directed toward factors in which further economies should be sought or can most easily be secured. The autopsy on an unfortunate process will usually reveal the principal cause of failure and will at least dictate the need of a new line of attack. If the product is already being made by another method, an estimate of the corresponding cost may wisely be attempted, since, however ingenious a new process, its competitive utility will be slight, if the cost is relatively high. Clearly, a cost estimate is the logical nucleus around which to gather data for the complete engineering report which the critical executive desires.

The importance of constructing a flow sheet before proceeding with the cost estimate cannot be overemphasized. The flow sheet, which should depict as completely as possible the process in its technical aspects, will minimize errors of omission and will serve to organize the whole project. Assumptions as to location of plant, yields, power and fuel consumption, labor requirements, and plant cost may be difficult to make, but someone must assume the responsibility before too much money is expended on what ultimately may be an uninteresting project.

In order that essential factors in project analysis may not be overlooked, a fairly comprehensive procedure is outlined in the following section of this chapter. Naturally, the exact composition of such an outline will vary with the type of industry. However, a simple standard guide is a constant aid, even to the experienced investigator.

As the research progresses in the laboratory, successive cost estimates are made, each in greater refinement, as warranted by the technical data. For example, a process was proposed for producing an inorganic salt. The preliminary experimental results were decidedly favorable, as were the cost estimates. In the light of further experiment, however, the revised cost estimates caused the project to be dropped. In this instance, the weak point was the unexpectedly high cost of purifying one of the

raw materials, a mineral. Moreover, considerable uncertainty arose regarding the adequacy of the mineral supply. Sometimes it is necessary for the investigator to exercise his imagination to the extent of evaluating a raw-material situation or a market situation 10 years or more in the future.

Capital Investment.—As noted in the outline, it is frequently necessary to estimate the capital requirements of a process that has never been operated commercially.

There are several ways of making such an estimate, the choice being dependent upon the state of the technical development and upon the desired precision. The ideal procedure is to hand the flow sheet to an engineering estimator with instructions to produce a detailed report. Sooner or later, this must be done if the process becomes increasingly interesting as the research progresses. Detailed estimates, however, require much time and money, and require information that may not immediately be available. Even in the early stages of a process development, estimators expect the research man to have every specification definitely in mind.

Another method of estimating the plant investment is based on comparative data. Assume, for instance, that the proposed process *A* is similar in principle to process *B*, which is in commercial operation. From knowing something of process *B*, a fairly close estimate for process *A* can be made. For example, the production of sulphate of ammonia by the wet neutralization process is quite similar to the production of ammonium phosphate from aqueous phosphoric acid and ammonia gas; therefore, the same plant costs may be used for both processes.

When it is difficult to draw reasonably close parallels between processes, an estimate can be based on the constituent unit operation and unit process equipment that will be required. For example, from a knowledge of the approximate outputs of equipment needed for such operations as crushing, leaching, filtering, evaporating, and drying, the over-all equipment cost can be built up. To this total can be added estimates for land, buildings, railway sidings, outside lines, storage, power plant, and material-handling machinery, all of which are generally well-known costs, available to anyone. For contingencies, 20 per cent is added, also 10 per cent for engineering and design. Such estimates are readily made and should be satisfactory for preliminary requirements.

If, for any reason, the foregoing methods are not applicable, it is always possible to revert to a rough-and-ready, though surprisingly reliable, rule that the average chemical plant investment is about $1.00 per $1.00 of factory value of product, and the limits will be about $0.75 to $1.25 per $1.00 of product. It may appear ridiculous to say that, assuming a capacity output of $1,000,000 per year, the plant cost will be about the same; nevertheless, it is close to being a fact, assuming the operation to be conducted at full capacity and on an economic scale. For example, such widely differing manufactures as calcium cyanamide, sulphuric acid, superphosphate, viscose rayon, and by-product coke all require a plant investment of about $1.00 per $1.00 of product.

In addition to the investment in plant, an enterprise needs working capital, which comprises, essentially:

1. Cash, equivalent to 30 days' operating expenses.
2. Bills receivable, equivalent to 30 days' sales.
3. Inventory, carried at factory cost.

Usually, an inventory allowance of 60 to 90 days' output is sufficient, although the variations are extremely wide. For example, a fertilizer manufacturer must carry an average inventory of 5 to 6 months' output; on the other hand, a manufacturer of anhydrous ammonia might carry only 10 to 20 days' output. It is difficult, therefore, to generalize regarding working capital. It varies from 20 to 100 per cent of the plant investment, with an average of about 50 per cent.

Market Survey.—Market surveys comprise the greater part of the average commercial research program. They are essential in planning production and should be made prior to any substantial expenditure for experimental work. If results of the preliminary survey are favorable, then further expenditure for research and development is better justified than on the prospect of favorable technical results alone.

The market survey is essentially a study of consumption and can be expressed by the following equation:

Consumption = stocks at beginning of period + production + imports entered for consumption − stocks at end of period − domestic exports.

When the consumption cannot be estimated directly from published data, the investigator has ample opportunity to

demonstrate his resourcefulness. For example, one procedure is to list all known uses of the commodity, after which the consumption is calculated by applying a factor for each use. The method depends, of course, upon the validity of the underlying data and assumptions. Thus, if the viscose rayon production in the United States is at the rate of 200,000,000 lb. per year, and the consumption of carbon bisulphide is 0.5 lb. per pound of rayon, then it follows that the industry consumes 100,000,000 lb. of carbon bisulphide. Such consumption factors as carbon bisulphide in viscose rayon manufacture are obtainable by reference to the literature, or by "sampling" some friendly company in the trade.

But the market survey is hardly begun when the total United States consumption has been estimated. A new producer should not expect to capture the entire market. The real interest centers in an estimate of the probable participation in the market. Analyses showing consumption by uses, by geographic areas (or freight territories), by industries, by individual consumers, and by seasons of the year, are much more revealing than is a statement of total consumption. In markets nearer to plants of competitors, there is a disadvantage as to freights. Some consumers may take their requirements during one or two months of the year; storage must be provided for it. When the foregoing factors have been considered carefully, the variation from total consumption may be tremendous.

Price Study.—When the proposed output of a product is small in relation to existing consumption, and when the plant location is logical, it can be assumed that the price situation will not be disturbed by the new output. Particularly is this true when the demand for the product is growing, as the new output eventually will be absorbed by an expanding market. The new output is strategically secure as long as its cost of manufacture and delivery is as low as the competitive cost or lower. Over the long term, chemical prices relate logically to costs, and, except temporarily, prices will not be lower than costs.

When, however, the new output is large in relation to existing consumption, or when it is proposed to displace other products, sales can be achieved only by virtue of lower price, higher quality, better service, or some combination of these factors. In such cases, the new output is strategically secure only as long

as the advantage is maintained. The nitrogen industry affords an excellent example: about 15 years ago, the production of anhydrous ammonia was 25,000,000 pounds a year, and was used largely for refrigeration. This ammonia was produced by purifying and stripping crude by-product ammonia liquor. The price in cylinders was 30 cts. a pound. With the subsequent development of the synthetic ammonia industry, the price was cut in half; in tank cars, the price in 1927 was 7½ cts. a pound, and by 1937 it was 4½ cts. a pound. Meanwhile, the primary production of ammonia has increased between tenfold and twentyfold.

Theoretically, a producer is free to sell at any price he chooses. Practically, the price is affected by demand factors and by competitive factors. If a price is too high in relation to costs, competition will come into play to reduce it to levels that permit only a reasonable return. In fact, the price histories of such staples as ammonia, alcohol, sulphuric acid, steel, and cement show that, over the long term, the return is less rather than more than a "reasonable return," as defined further on in this chapter. That is because a staple field always attracts the strongest competition, and once the competition is established, it rarely disappears.

Seemingly, a different case is exhibited by the so-called patent monopolies. Actually, the case is no different from the patent-free field. The same fundamental factors of demand and competition operate, though perhaps not so clearly. The possessor of a patent monopoly first has to write off the expense incurred during the period of development and sales introduction. As stated in Chap. III, this period is about 10 years. By the time the development expense is returned, the manufacturer finds that only a few years, if any, of the monopoly remain. During the life of the monopoly, competition is not free, yet it must be regarded as latent or potential competition. That is, the wisest course is to proceed as though no monopoly existed. Prices should be set at levels that will insure the maximum over-all return rather than the maximum return per unit of sale. Thus, when the monopoly expires, prices will be so low as not to be especially interesting to potential competitors.

The price history of a product is of interest when compared with projected costs, as it indicates the probable maximum profit

margin. In addition, the following price levels should be estimated:

1. The price at which imports, if any, would practically be shut out. Normally this price would be the sum of the production cost in the country of origin, freight and handling, import duty, and selling expense. For example, the price at which synthetic methanol ceased to be imported from Germany was about 50 cts. a gallon.

2. The price at which the product would be used more extensively for present purposes, or be substituted for other products. For example, a certain relatively small quantity of methanol would be used at a price of $1.00 a gallon. It would, no doubt, be used in making synthetic dyes, flavors, and medicinals in which the methyl group is needed. It would be used in making formaldehyde for embalming and for a few synthetic organic chemicals. At 50 cts. a gallon, the use would be much larger than at $1.00, as the use of formaldehyde in resins would be greatly expanded. It would not, however, be used as an antifreeze. At prices between 30 and 40 cts. a gallon, methanol becomes competitive with denatured alcohol, especially for antifreeze. At the 1927 price of 60 to 70 cts. a gallon, the consumption of methanol was about 6,000,000 to 7,000,000 gallons a year, whereas at prices of about half the 1927 level, the consumption has increased fivefold.

Return on Investment.—Having estimated production cost, markets, prices, and capital investment, the rate of return on the investment is calculated as follows:

$$\text{Per cent rate of return} = \frac{(\text{Unit price} - \text{cost of sales}) \times \text{volume of sales} \times 100}{\text{capital investment}}$$

The rate of return must be at least 3 to 4 per cent in order to break even, since high-grade bonds yield this return over a period of years. The stockholder, however, is entitled to a higher average annual return, say 6 per cent, in order to compensate for the added risk. In order to pay the stockholder 6 per cent a year, an investment must return 10 per cent a year, since 40 per cent of earnings should be set aside as surplus, largely for pioneering research, process development, improvements, and extensions. Even under the most favorable circumstances, industry has lean

years, so that an average return of 10 per cent a year on the investment is about as much as is earned by the well-established chemical companies. In order therefore, to compensate for lean years, the expected return for capacity operation should be set at not less than 15 per cent. In a stringent money market, 20 per cent is a more conservative figure.

Various exceptions will come to mind. An expectation of ultimate substantial reductions in cost may justify an initial commitment at 10 per cent return or less. Possibly it is desirable or essential to provide an internal source of supply for a commodity, in which case merely break-even performance may be justified. Such exceptions, however, cannot be anticipated, nor can rules be formulated regarding their disposition.

OUTLINE FOR PROJECT ANALYSIS[1]

I. Derivation of flow sheet.

1. Statement of reactions upon which process is based: A full explanation of the chemistry of the process.
2. Description of process: A general statement of the process, including each of the various steps.
3. Block-form flow sheet: An elementary flow sheet of the process as outlined in the preceding paragraph.
4. Calculation of flow-sheet quantities:
   a. Selection of unit basis for calculation.
   In treating gas volumes it is convenient to use a volume unit of 100 cu. ft., based on the raw gas entering the process. In treating solids it is convenient to use either 100 lb. or 100 mols of the raw material. In certain cases it may be advisable to use a unit based on an intermediate product or on a finished product.
   b. Application of necessary assumptions.
   The various assumptions which are necessary for calculating the flow sheet should be tabulated, in order that the assumed conditions may be clearly understood.
   c. Application of experimental data.
   All experimental data not included in the statement of reactions should be reviewed with reference to the practicability of the process.
   d. Calculation of flow sheet.
   Any calculation relating to the flow-sheet derivation should be fully explained.
5. Tabulation of flow-sheet quantities: A complete tabulation of quantities and compositions based on the steps outlined in the description of the process.

[1] Adapted from an outline developed by R. L. Dodge.

II. Design of plant.

1. Factors in choice of plant capacity:

   a. Quantity of raw material available.

   b. Quantity of finished product to be manufactured.

   c. Capacity of process units.

   For example, in treating gas volumes it is convenient to use the capacity of a single compressor unit as a basis. It is not advisable to use a fraction of a compressor unit, but the use of multiple units may be desirable. In general, the use of standard unit capacities will result in considerable savings in cost of plant.

2. Derivation of a multiplier for quantities in the unit flow sheets in order to transform them to plant quantities: Since the unit flow sheet is based on 100 cubic feet, 100 mols, or a similar unit at some stage in the process, the derivation of the flow sheet for the plant is readily accomplished by using an appropriate multiplier based on the ratio of the units used in the flow sheet to the plant capacity at the same stage of the process.

3. Study of individual steps in process:

   a. Determination of conditions necessary to effect desired results.

   (1) Thermal considerations.
   (2) Equilibria, or yields.
   (3) Solubilities.
   (4) Auxiliary requirements.
   (5) By-products.

   Each of the steps in the process should be considered in the light of the foregoing factors. It may be found convenient to subdivide each of the steps mentioned in the description of the process into smaller unit steps in order to illustrate the calculations more clearly.

   b. Design of equipment.

   c. Pressure losses.

   d. Heat losses.

   e. Material losses.

   f. Power requirements.

   (1) Electric.
   (2) Steam.

   In considering equipment design it is necessary to strike a balance between detailed design and rough estimates. Since most paper studies are preliminary, it is not usually advisable to make a detailed design. It is, however, necessary to obtain sufficient data to estimate costs of the various pieces of equipment. This distinction may be illustrated by stating that it is necessary to calculate the area of heating surface in preheaters, but is not necessary to design the pipe lines leading to and from the preheaters. It is neither appropriate nor desirable to design involved mechanical devices for accomplishing well-defined objectives.

   g. Summary of all quantities for each step.

   This is a tabulation of the quantities for each step, including a list of the equipment required.

4. Block flow sheet showing all quantities and temperatures: This flow sheet should illustrate the entire plant. It should show the entrance

and exit temperatures for each step of the process, and the heat quantities.

III. Derivation of cost estimate.

1. Investment for equipment required in each step, including 20 per cent for contingencies and 10 per cent for engineering and design: The investment should be summarized from the equipment list. It should show the equipment at present installed and the estimated cost of any new equipment which is required.

   For wholly new and untried operations, 20 per cent should be taken for contingencies; for operations duplicating or similar to present operations, 10 per cent is ample.

The investment should include working capital, as follows:

a. Cash equivalent to 30 days' mill cost.
b. Accounts receivable equivalent to 30 days' sales.
c. Inventory of finished product carried at cost. This should be the average inventory required for 12 months' operation.

2. Summary of investment:
   a. Land, including such improvements as roads, fences, railroad sidings, docks, and parking space.
   b. Buildings complete with such necessary services as heat and ventilation, and connections for water, power, steam, sewer. Also investment in buildings for finished-product storage, raw-material storage, and fuel storage.
   c. Process equipment, including auxiliary equipment, as for example, water-purification plant.
3. Operating cost:
   a. Ingredients.
   b. Services.
      (1) Electric power.
      (2) Steam.
      (3) Water.
   c. Direct supervision.
   d. Direct labor.
   e. Repair labor and materials.
   f. Supplies.
   g. Works expense.
   h. Fixed charges.
      (1) Taxes and insurance.
      (2) Depreciation.

In each case where the item is a percentage of the investment or of the direct labor, the percentage should be shown. This applies to repairs, works expense, and fixed charges.

4. Determination of unit-process cost of product: This cost applies to the product as issued from the process and includes no storage, handling, packing, or other charges.
5. Determination of unit-process cost of product f.o.b. plant:
   a. Packages.
   b. Packing.
   c. Loading.

It is usually necessary to make some assumption regarding the packages in which the product is to be marketed and the stock which is to be maintained. If market surveys are at hand, the type of container can be specified. The amount of stock which must be carried will be determined by the capacity of the plant and the buying habits of the trade.

6. Determination of the price to yield a given return on investment, or the return on investment yielded at various prices: Ordinarily, a return of 20 per cent on the full investment should be used in this calculation.
7. Determination of the effect of varying the cost of one or more ingredients on the final product cost: This need be shown only for important ingredients.

IV. Market survey.

1. Description of product:
   a. Physical and chemical properties.
   b. Physiological action.
   c. Shipping classification.
2. Standard specifications:
   a. Definition of grades.
   b. Limits of impurities and of physical properties, for example, specific gravity, color.
   c. Packing specifications.
   d. Possibility of improving quality.
3. Consuming industries:
   a. Total consumption and value.
   b. Distribution of consumption by industries and by geographical areas.
   c. Distribution of consumption by important individual consumers, when information available.
   d. Exports.
   e. Possibility of developing new uses.
4. Buying habits of consuming industries:
   a. Contracts, and basis of quotations.
   b. Sales methods now in use.
   c. Possible substitutes and market conditions governing choice.
   d. Seasonal or fluctuating demand.
   e. Wide market or restricted to few consumers.
5. Production statistics:
   a. Domestic production and trend of production.
   b. World production, and production by specified countries.
   c. Production by principal individual producers, when available.
   d. Imports for consumption.
   e. Stocks on hand.
6. Competitive situation:
   a. Principal competitors, their location, and capacity.
   b. Near-by markets.
   c. Imports, and dependence of domestic industry on tariff protection.

   d. Trends and possibility of new processes.
7. Freight tariffs from principal producing centers to principal consuming centers:
8. Comparison of manufacturing processes:
   a. Raw materials: sources, reserves, availability.
   b. Fuels and power.
   c. Labor.
   d. Capital investment.
   e. Yields.
   f. Costs of production.
   g. Importance of by-products.
   h. Health hazards.
9. Probable future markets:
   a. Trend of consumption.
   b. Trend of prices.
10. Patent situation and other legal restrictions on manufacture, sale and use.

SOURCES OF COMMERCIAL INFORMATION

The well-trained engineer is thoroughly familiar with the technical literature of his chosen branch. He uses textbooks, reference books, handbooks, technical periodicals, transactions of technical societies, technical abstracts, and the "Engineering Index." He is not generally familiar, however, with the sources of commercial information beyond, perhaps, the daily newspapers, journals of commerce, industrial and trade periodicals, catalogues, and the United States Census of Manufactures. Yet, as the engineer progresses in an industrial organization, his work broadens, and the commercial aspect of it becomes increasingly important. He will need, therefore, a working knowledge of such commercial information as production and consumption statistics; foreign trade statistics; price statistics; production costs; marketing costs; tariffs; transportation costs; uses of products; and sources of raw materials.

As pointed out by De Long,[1] the published data of domestic production are fairly complete, the following numbered paragraphs being an abstract of his discussion of sources of commercial information:

The principal first-hand sources of production data are as follows:

[1] *Chem. Met. Eng.*, **36**, 8 (1929).

1. Bureau of the Census: Census of Manufactures—biennial. Monthly, quarterly and semiannual statements on selected industries.

2. Bureau of Mines: Mineral Resources—annually. Minerals, metals, salts and other products obtained by direct processing of the ores.

3. U. S. Tariff Commission: Census of Dyes and Synthetic Organic Chemicals—annually. Reports on special commodities, especially under Section 315 (flexible provisions) of the Tariff Act of 1922.

4. Trade Associations: Some associations collect and publish production figures, in some instances in cooperation with the Bureau of the Census.

Only in relatively few instances have consumption data been published by government departments. The following examples may be mentioned:

1. Factory consumption of oils and fats, by the Bureau of the Census.

2. Consumption of chemicals in the flotations of ores, by the Bureau of Mines.

3. Consumption of chemicals in the preserving of timber, by the Department of Agriculture.

Regarding heavy chemicals, reliable estimates of production, consumption, and uses have been published from time to time by *Chemical & Metallurgical Engineering.*[1]

Information regarding the location of producing units can be assembled from various sources. These include catalogues, buyers' guides, advertisements in trade and technical journals, and corporate reports to stockholders.

The Bureau of Census now publishes for individual chemicals the number of establishments by states, which, supplemented by information from other sources, is extremely useful. Regarding dyes and synthetic organic chemicals, the annual census of the Tariff Commission gives accurate information as to the producers of each product.

The record of imports and exports is published regularly by the Department of Commerce. Monthly imports of dyes are published jointly by the Chemical Division of the Department of

[1] See especially the "Annual Review" numbers, also the "Facts and Figures of American Chemical Industry," September, 1937.

Commerce and by the Tariff Commission. In addition, certain trade journals and business newspapers publish import data by ports. These data may or may not be accurate, as they are taken from the "Ship's Manifest" filed at each port. Their accuracy depends largely on the completeness of the designation on the manifest. They must, therefore, be used with caution. In all instances, the fallacy of accepting statistical data at face value should be emphasized. In order to get the most out of such data, the investigator must be thoroughly familiar with the sources. He must learn how they are compiled and whether they represent the whole industry. He must know statistical sources as intimately as the technical man knows the source and reliability of the technical information he uses in his engineering calculations.

Developing the subject in further detail, the following outline includes many sources of information commonly used in making market surveys and cost estimates:

Department of Commerce

Bureau of the Census

Census of manufactures including various groups of the chemical and allied industries (biennial): Reports for the census are issued by industries (for 5 cts. each), states and cities (free).

The reports on manufactures include statistics regarding the number of establishments, number of salaried officers and employees, number of wage earners, total salaries and wages paid, cost of fuel and electric energy, value of products, and value added by manufacture, by states and for principal cities, and for principal industries.

Vol. 1, Manufactures: General report; statistics by subjects. (Available in libraries only.)

Vol. 2, Manufactures: Reports by industries. $3.00.

Vol. 3, Manufactures: Reports by states; statistics for industrial areas, counties, and cities. (Available in libraries only.)

"Distribution of Sales of Manufacturing Plants." 15 cts.

Miscellaneous Monthly Reports:

"Cellulose Plastic Products": Nitrocellulose and cellulose acetate sheets, rods, and tubes. Issued 25 days after end of month.

"Methanol and Acetate of Lime": Production, shipments, and stocks of acetate of lime and refined methanol; production and stocks of crude methanol; consumption and stocks of wood and active capacities. Issued 45 days after end of month.

"Paint, Varnish, and Lacquer Products": Sales. Issued 40 days after end of month.

"Sulphuric Acid" (reported by fertilizer manufacturers): Production, shipments, consumption, purchases from non-fertilizer manufacturers, and stocks. Issued 40 days after end of month.

"Superphosphates" (reported by fertilizer manufacturers): Production, shipments, and stocks. Issued 45 days after end of month.

Annuals: (Available from the Bureau only.)

"Pulpwood and Wood Pulp": Consumption of pulpwood by states and by species; production of wood pulp, by states and by processes. Preliminary report, May. Final report, September.

"Clay-Products Industries and Sand-Lime Brick": Production and stocks, by classes of products and by states.

"Fats and Oils, Animal and Vegetable": Factory consumption of primary fats and oils, by classes of products in which used. April.

Bureau of Foreign and Domestic Commerce

"The Foreign Commerce of the United States": A monthly summary of statistical tables including imports and exports of various commodities; countries of origin and destination. Includes, for instance, such commodities as nitrate of soda, chloride of potash, anhydrous ammonia, phosphate rock, acetic acid, alcohol.

"World Trade Notes on Chemicals and Allied Products": A weekly series published by the Chemical Division. Includes statistics of production, consumption, trade, cost, price, and use; also current information regarding new processes, new products, corporate earnings, plant construction. Contains inclusive and prompt news of world chemical industry.

"World Chemical Developments": *Annual Trade Information Bulletin.* Contains summaries for all principal powers, including U. S. A., Great Britain, Germany, France, Italy, Japan.

"Survey of Current Business": Published monthly. Includes principal figures for the basic industries and trade of the United States, showing comparative changes in production, prices, sales, stocks, distribution, employment, and other factors of business conditions.

"Statistical Abstract of the United States": Annual volume of about 800 pages. Contains condensed tables of the statistics collected by government agencies on all forms of activity and progress in the United States. $1.50.

National Committee on Wood Utilization:

"Chemical Utilization of Wood": 1932. Includes discussion of sawdust, wood flour, chemical wood pulp, wood distillation, and naval stores, tannin, and wood extracts, sulphite waste liquor, and wood carbohydrates.

Department of the Interior

Bureau of Mines

Information Circulars:

"The Fertilizer Industries," *Information Circular* 6834, 1935.

"Minor Fertilizer Materials," *Information Circular* 6830, 1935.

"Calcium Chloride," *Information Circular* 6781, 1934.

"Chalk, Whiting, and Whiting Substitutes," *Information Circular* 6482, 1931.

"Economics of Potash Recovery from Wyomingite and Alunite," *Reports of Investigations* 3190, 1932.

"Limestone," *Information Circular* 6437, May, 1931.

"Nitrogen and Its Compounds," *Information Circular* 6385, 1931.

"Potash," *Economic Paper* 16, 1933.

"Pyrites," general information, *Information Circular* 6523, 1931.

"Sodium Sulphate," *Information Circular* 6833, 1935.

"Petroleum Refineries in the United States," *Information Circular* 6728, 1933.

"Petroleum Refineries, including Cracking Plants, in the United States," Jan. 1, 1934.

"Bismuth," *Information Circular* 6466, 1931.

"Chromium," general information, *Information Circular* 6566, 1931.

"Sodium and Potassium Metals," *Information Circular* 6579, 1932.

Statistical References:

"Minerals Yearbook." Contains approximately 60 chapters, dealing with the production and general economics of the commercial minerals. The various chapters also are issued separately.

Monthly statistical statements include:

Production, shipments, and stocks of Portland cement.

Production and stocks of crude petroleum and refined products.

Market and transportation conditions, prices, and labor supply in the coal industry.

"Coke and By-products." Includes by-product coke, gas, tar, oils, sulphate of ammonia, ammonia liquor.

Natural gasoline production.

World retail prices of gasoline, kerosene, and automotive lubricants.

International petroleum trade.

International coal trade.

Weekly statements are issued on production and distribution of coal and coke.

Department of Labor

Bureau of Labor Statistics

Cost of Living:

Once every quarter, for the months of January, April, July, and October, agents of the Bureau collect prices in 32 large cities for clothing, furniture, and house furnishings; drugs and toiletries; rents, and mechanical goods and services such as cleaning supplies; transportation; medical care, and recreation. The prices so collected are used in computing index numbers of cost of living.

Wholesale Prices:

Including chemicals and drugs. These reports are issued weekly and monthly, and are published in the *Monthly Labor Review* and also in a separate pamphlet.

Trend of Employment and Pay Rolls:

The industrial employments for which data are obtained include 90 manufacturing industries and certain nonmanufacturing industries. Indexes of employment and pay rolls are published monthly.

National Resources Committee

"Technological Trends and National Policy," 1937.
(Section VI, "The Chemical Industries.")

Tariff Commission

The Commission has issued numerous reports of investigations relating to chemical commodities and industries, as for instance, reports on methanol, the nitrogen industry, potash, vegetable oils.

Production and Sales of Dyes and Other Synthetic Organic Chemicals. (Annual report.)

Trade Directories and Catalogue Services

Breskin & Charlton Publishing Corp. (425 Fourth Ave., New York)

"Plastics Guide Book" (published annually): Contains names and addresses of concerns manufacturing and selling chemicals, raw materials, machinery and equipment for the plastics industry. The suppliers of plastic materials, fabricators and molders, products manufactured wholly or in part from plastics and the manufacturers of these, also are included.

Chemical Industries, Inc. (149 Temple St., New Haven, Conn.)

"Chemical Guide Book" (published annually in cooperation with *Chemical Industries*): Contains the following information for buyers and sellers of chemical products:

Part I. A consolidated catalogue of manufacturers of chemical products.

Part II. An alphabetical list of chemicals, essential and fatty oils, pigments, and other chemical raw materials, together with trade names and chemical symbols, arranged alphabetically. Various commercial grades, types of containers, usual trade quantities, and shipping regulations are included, and, in most cases, import tariffs.

Part III. Manufacturers and dealers of the products specified, arranged geographically with street addresses and telephone numbers.

Part IV. Back prices and statistics on 100 important chemicals, including intermediates and oils.

The Druggists' Circular (12 Gold St., New York)

"The Red Book Price List and Buyers' Guide" (published semiannually, in November and May): Lists wholesale and retail prices of 100,000 drugs,

chemicals, pharmaceuticals, biological products, proprietaries, toilet, and miscellaneous preparations, with the names of manufacturers.

India Rubber World (420 Lexington Ave., New York)

As a part of the monthly journal *India Rubber World* there is a "Buyers' Directory" containing alphabetic listings of rubber materials and machinery used in the rubber industry, together with the names of concerns which supply these commodities.

Industrial Publications, Inc. (59 E. Van Buren St., Chicago, Ill.)

"Ceramics Catalog": Contains data, arranged in cyclopedic form, relative to equipment, materials, and processes employed in the manufacture of ceramic wares (including glass, enamel, pottery, terra cotta, brick, and tile products).

Lockwood Trade Journal Co., Inc. (10 E. 39th St., New York)

"Lockwood's Directory of the Paper and Allied Trades" (published annually): Includes lists of paper, wood-pulp, and chemical-fiber mills; mill equipment, kind of power used, and products manufactured; grades of paper stock and rags consumed, together with the name of the purchasing agent. A section is devoted to the sources of supply for machinery and raw materials used in this industry.

Oil, Paint & Drug Reporter (12 Gold St., New York)

"The Green Book Who's Who" (published annually): Lists buyers, and sellers in the chemical, dyestuff, drug, paint, oil, fertilizer, and related industries.

Reinhold Publishing Corp. (330 W. 42d St., New York)

"Chemical Engineering Catalog" (published annually in September): Contains catalogue data of manufacturers and producers of chemicals, chemical engineering equipment, general engineering equipment, and supplies.

Thomas Publishing Co. (461 Eighth Ave., New York)

"Thomas' Register of American Manufacturers" (published annually in December): An extensive register arranged alphabetically, by commodities, and geographically. Gives approximate financial rating (size, not credit rating).

Ware Bros. Co. (1330 Vine St., Philadelphia, Pa.)

"The American Fertilizer Handbook" (published annually under the direction of *The American Fertilizer*): Contains a directory of fertilizer manufacturers; a buyers' guide of the allied fertilizer trades, and lists of fertilizer machinery, factory construction, equipment, and supplies; fertilizer materials, feed-stuffs, brokers, exporters, importers, and commission merchants.

Business Services

Brookmire Corporation (551 Fifth Ave., New York)

Studies are made of income and of consumer purchasing power, merchandising, and finance. The income studies have as their particular object the determination of current income classified by localities and economic groups; estimates by counties are included.

Business Branch of the Public Library (34 Commerce St., New York)

A series of handbooks planned to provide businessmen with condensed guides to a wide range of business references.

Dun & Bradstreet, Inc. (290 Broadway, New York)

Dun & Bradstreet Monthly Review: A monthly review of business conditions in the United States and Canada, supplemented by a weekly review.

Research and Statistical Surveys: Include "Retail Survey," "Wholesale Survey," and "Manufacturing Survey," based on questionnaire returns.

Market Research Corporation of America (1250 6th Ave., New York)

This company carries on specific investigations and analyses of trade and consumer investigation, delineation of trading areas, product tests in the field, sales quotas, and many other types of market research, mainly for clients.

Moody's Investors Service (65 Broadway, New York)

"Investment Survey": Includes statistical bulletins on general business conditions and positions of specific industries; special analyses and reports on markets, consumption, and their potentialities.

"Moody's Manual": Published annually, supplemented twice weekly. Consists of the following five volumes: "Industrials"; "Public Utilities"; "Steam Railroads"; "Banks, Insurance, Real Estate, and Finance"; "Government and Municipals." While these volumes are essentially reference books on corporate finance, operations, and securities, they contain, for each company, data on sales, plant facilities, location of properties, and products.

Monthly data are published, including an index of potential purchasing power in the United States; "prosperity" index; and an analysis of supply and demand in connection with major commodities, such as copper and automobiles.

Special Libraries Association (345 Hudson St., New York)

"Guides to Business Facts and Figures." Includes statistical compilations, handbooks, indexes, glossaries, and bibliographies.

"Statistics of Commodities": Chart acting as a master key to the current statistics published regularly in 77 magazines covering 104 basic commodities.

"Trade Catalog Collection": A Manual with Source Lists. Lists directories of manufacturers; condensed catalogues; trade catalogues worth

considering as manuals and handbooks; periodicals with lists of current trade catalogues; and house organs.

Standard Statistics Co., Inc. (345 Hudson St., New York)

As a part of the Standard Trade and Securities Statistical Edition, the following statistical studies are published:

Earnings Bulletin (issued monthly): Contains reports of earnings of more than 900 companies.

Statistical Bulletin (published annually and monthly): Data on production, consumption, stocks, and prices for leading industries; banking and finance; crops and foods; employment and wages; and railroads.

A weekly forecast and analysis of general business is made; also frequent analyses and forecasts are made for 41 different industries and security groups, as well as for general financial conditions.

Chambers of Commerce

Nearly all large chambers of commerce are prepared to supply information regarding statistics of natural resources, production, consumption, power supply, labor supply, transportation. Such information is particularly helpful in making market studies and plant-location studies. Similar information usually is obtainable from the industrial development departments of large railroad systems and of state governments.

Periodicals

Aside from the periodicals already noted, mention should be made of periodical files which contain a wealth of statistical information. Thus,

Chemical & Metallurgical Engineering (McGraw-Hill Publishing Company, Inc., New York) publishes each year a review of economics and statistics relating to the chemical and allied industries. This now appears in February.

Industrial and Engineering Chemistry (American Chemical Society, Washington, D. C.) publishes numerous articles containing statistical and economic information.

Chemical Industries (New Haven, Conn.) similarly contains a wealth of information useful to the market investigator.

Oil, Paint and Drug Reporter (New York) is a weekly publication and contains inclusive price information. Contains also information relating to current exports and imports, taken from ships' manifests.

There are numerous other useful periodical publications each in a definite fields such as *Modern Plastics; Oil and Gas Journal; The American Fertilizer; India Rubber World; Coal Age; Rayon Organon; Soap.*

Trade Associations

American Petroleum Institute (50 W. 50th St., New York)

Reports of production and consumption of petroleum and its products. Cost studies.

Bureau of Raw Materials for American Vegetable Oils and Fats Industries (1251 National Press Club Building, Washington, D. C.)

Production and consumption statistics are collected; also, records are kept of prices of fats and oils.

Compressed Gas Manufacturers Association (11 W. 42d St., New York)

An association of manufacturers of such compressed gases as ammonia, carbon dioxide, sulphur dioxide, acetylene, oxygen, hydrogen, chlorine, nitrogen, nitrous oxide.

Institute of Makers of Explosives (250 Park Ave., New York)

Private statistical studies regarding production and use of commercial explosives.

Manufacturing Chemists Association of the United States (Woodward Building, Washington, D. C.)

The trade association of chemical industry proper. Private statistical studies.

National Fertilizer Association (616 Investment Building, Washington, D. C.)

An index of wholesale prices of all commodities, based on 476 price quotations, and giving indexes for 14 groups of commodities, is compiled and issued each Monday for the preceding week.

Trade statistics are issued monthly on production, shipments, and stocks of superphosphate; sale of fertilizer tax tags in 17 states; movements of imports and exports of fertilizer and fertilizer materials; also letters discussing commodity price trends and general business conditions.

An annual review of conditions in the fertilizer industry, discussing sales trends and industry outlook, is published in the proceedings of the annual convention.

Articles on developments in the fertilizer industry, on agricultural purchasing power and related topics, are published in the bimonthly periodical, *The Fertilizer Review.*

Annual data on consumption of fertilizer in each state are published in *The Fertilizer Review.*

Rubber Manufacturers Association, Inc. (444 Madison Ave., New York)

Monthly and quarterly statistics are compiled on shipments, stocks, prices, and consumption of rubber goods.

Synthetic Organic Chemical Manufacturers Association (260 West Broadway, New York)

An association of manufacturers of dyestuffs, intermediates, pharmaceuticals, photographic chemicals, and other synthetics. Private statistical studies.

U. S. Pulp Producers Association (122 E. 42d St., New York)

Monthly statistics on shipments, stocks, sales, consumption, and production of wood pulp.

CHAPTER V

PLANT LOCATION

Of the many factors bearing on plant location, the following are generally conceded to be fundamental, irrespective of the exact nature of the enterprise:

1. Source of raw materials.
2. Market for finished products.
3. Source of fuels and power.
4. Labor supply.
5. Transportation facilities.
6. Relation to other industries.
7. Capital requirements.

In no two industries are the foregoing factors likely to have equal weight. Their relative importance varies widely, therefore each problem requires that every known location factor be carefully evaluated.

Source of Raw Materials.[1]—When the bulk value of the raw materials is low, the source of supply is an important factor in plant location. The classic example is the iron and steel industry, the locations of which have been determined only after much painstaking study.

In order to produce 1 ton of pig iron, about 4 tons of raw material is required, namely 2 tons of ore, 1½ tons of coal (to make 1 ton of coke), and ½ ton of flux (limestone). These basic raw materials occur in large quantity in many parts of the world. The smelting, however, is economically feasible only at points where the ore, coal, and flux can be assembled cheaply. Thus, the country's largest iron-ore smelters are in Alabama, Illinois, Michigan, Ohio, and Pennsylvania. In parts of Alabama and Pennsylvania, all three raw materials occur in the desired grades and quantities. Nearly 90 per cent of American ore, however, comes from the Lake Superior region, at points where there is no coal. Therefore, the Lake Superior ore is shipped to smelters in the Chicago, Cleveland, Buffalo, Youngstown, and Pittsburgh

regions, where it is assembled economically with the coal and flux. Such long hauls of ore are feasible because of low-cost transportation by water or by water and short rail hauls.

In 1936, the United States production of pig iron was about 30,000,000 tons, requiring about 120,000,000 tons of raw materials. Such figures indicate why seemingly insignificant savings per ton of raw material actually are tremendously important. Thus, each 10 cts. per ton increase in the cost of raw materials means 40 cts. per ton of pig iron, or 2 per cent of the price when the price is $20 per ton. Stated in another way, the increased cost to the industry as a whole would be $12,000,000 a year.

Following are other examples of industries in which raw-material source is especially important in determining plant location:

1. The wood pulp industry, in which more than 2 tons of high-grade pulpwood is required to make 1 ton of chemical pulp. In this instance, the pulp mills are located as close to the wood supply as is practicable, in view of water supply, cheap power, and adequate transportation; or they may be located relatively far from the wood supply, if water transportation is available.

2. The cement industry, in which the bulk value of raw materials, limestone and clay, is less than $1.00 a ton at the source. The typical cement mill is located at the source of raw materials.

3. The Solvay-process soda industry, in which the raw materials again have a bulk value of less than $1.00 a ton at the source. The typical soda plant is located at some source of salt (either as brine or as solid salt) where limestone also is obtainable at low cost.

4. The sugar industry, in which the crude sugar must be produced virtually at the raw-material source. Six tons or more of beets and 8 tons or more of cane are required to make 1 ton of crude sugar. Moreover, the sugar-bearing raw material is perishable.

5. A special case, of interest because it represents an extremely low bulk value of the raw material and an extremely high ratio of raw material to product, is the Ethyl-Dow Corporation bromine plant, Wilmington, N. C. Here, the raw material is sea water containing 67 parts per million (0.0067 per cent) of bromine. Even with theoretical yields, 7½ tons of sea water would be required to produce 1 pound of bromine.

Permanency of raw-material supply is a factor not to be overlooked, as has been pointed out by Kelsey:[1]

> The source and permanency of raw materials are usually among the most important controlling factors in deciding upon a location. A dependable supply of the proper quality of raw products must be assured.
>
> I have in mind a plant built in the East, designed to reclaim a certain waste material produced by the large brass mills in the same general territory. The plant was located near the source of its raw product and was operated profitably. The management decided that the same type of plant, though of smaller capacity, located in a city in the Middle West would also prosper. They failed to ascertain the amount which could be had of their raw product nor did they inquire with sufficient care into the location. As a result, it proved to be, first, so far from their factory that they could not afford to pay the heavy transportation charge, and second, the amount of raw material available was not sufficiently great to permit operating their plant to capacity, even though it could be economically assembled. This particular plant was a financial failure from the day it was completed, and the whole blame lies at the door of the management in failing to make a thorough and proper analysis of their most important raw material.
>
> A number of large and important industries operating today are feeling the pinch of freight rates on their raw materials. When the present sites were selected, the raw materials were, in most instances, relatively close at hand. These sources have, in a great many cases, become exhausted and the industries are now forced to go great distances for them, which means competition with plants making similar products located near their basic materials, and the competition grows keener each year.

Water as a Raw Material.—In several of the chemical process industries, water is virtually a raw material, being a carrier of the materials in process, or else actually entering into the product; hence, such factors as the following must be considered:

1. Quantity of water available.
2. Quality, as determined by mineral matter in solution or in suspension, or by organic pollution.
3. Temperature of the water.

For example, in the manufacture of wood pulp and paper, large quantities of relatively pure water are needed, and failure to heed this requirement has spelled ruin for at least one plant that was

[1] *Chem. Met. Eng.*, **25**, 401 (1921).

located advantageously in every other respect. In the gelatin industry, abundant water free from pollution is essential. Low temperature is important when water is used in condensers and scrubbers. For example, in one plant, liquid anhydrous ammonia is produced directly from the converter gas in condensers cooled by river water. In the midwinter when the water temperature is 35°F., the capacity of the ammonia plant is from 5 to 10 per cent greater than in midsummer, when the water temperature reaches 80°F.

Referring again to the Ethyl-Dow bromine plant, Wilmington, N. C., Stewart[1] gives the reasons for choosing this particular location:

> Geographical location was the chief reason for building the Ethyl-Dow plant on the peninsula extending south from Wilmington, N. C. With the Atlantic Ocean on the east side of the peninsula and the Cape Fear River on the west side, the location was ideal for pumping undiluted and uncontaminated sea water only a short distance to the bromine extraction plant and discharging the effluent into the river, which would take it back to the ocean far enough away so as to avoid contamination of the incoming water.
>
> The geography of the plant site also provides water and air of moderate or warm temperature throughout the year. From the standpoint of operating efficiency, this is an advantage which could not be obtained from locations in the northeastern states.

As chlorine is used in this process for liberating the bromine, it was essential that the sea water at the plant site contain an absolute minimum of organic matter, sewage, or industrial wastes capable of absorbing chlorine. It was necessary, further, to locate at some point where the near-shore concentration of bromine is at or near the maximum (67 parts per million), hence undiluted by fresh-water streams.

Publications of the Geological Survey[2] describe in detail the quantity, quality, and temperature of waters in various parts of the country.

Market for Products.—The location of a small plant frequently is determined entirely by market considerations. Thus, the higher production cost of the small plant is offset by low delivery

[1] *Ind. Eng. Chem.*, p. 301, April, 1934.

[2] Collins, "Temperature of Water Available for Industrial Use in the United States," *U. S. Geol. Survey, Water Supply Paper* 520-F.

expense and low selling expense. At first, such a plant is purely a local institution; with increased output, however, its marketing area is extended, until ultimately a business of national scope may be attained.

In several chemical industries, proximity to the market is essential to success. One example is the manufactured gas industry, in which the solid raw material—bituminous coal—can be brought to the gas-consuming centers at reasonably low cost, whereas the gaseous finished product would require an inordinate investment in pipe lines, boosters, and accessory equipment for transport to a distant market. In the sulphuric acid industry, it is feasible to transport the raw material farther than the product, the distribution of which is economical only within restricted areas of consumption, because of highly competitive conditions within the industry, low bulk value, and high freight rates. In the explosives industry, plants should be as near as practicable to the market, because of high freight rates. On the other hand, the potentially hazardous nature of explosives manufacture precludes locations adjacent to other industries and in densely populated areas.

TABLE II.—PLANT LOCATION AND AREA OF CONSUMPTION

Location of plant	Principal products	Principal outlet for products
Barksdale, Wis.	High explosives	Iron ore mines in Lake Superior region
Nemours, W. Va.	Black powder	Coal mines in West Virginia and Kentucky
S. San Francisco, Calif.	Paint, varnish, lacquer	West-coast general local market
El Monte, Calif.	Liquid hydrocyanic acid	Fumigant for citrus trees in southern California
East Chicago, Ind.	Acids, heavy chemicals	Steel, oil refining, and other industry in Chicago region

The du Pont Company has located many of its plants primarily with respect to areas of consumption, as indicated by the examples shown in Table II.

Source of Fuels and Power.—In most chemical industries, source of fuels and power does not rank with raw-material source and markets as a location factor. In a few of them, however, such as pulp and paper, portland cement, glass and clay products, it has great importance; and in one branch, electrochemicals, it is dominant. Thus, Niagara Falls has become a center of the electrochemical industry, producing calcium carbide, carborundum, caustic soda, chlorine, graphite, and sodium metal at low cost. But cheap power is not the only essential for success in electrochemical manufacturing—the power must be at the right place. Thus, at Niagara Falls, raw materials and markets are near, transportation facilities are excellent, and an abundance of good labor is obtainable.

In order to show how the factor of fuel and power varies from one industry to another, a few examples[1] are given in Table III.

TABLE III.—RELATION OF FUEL AND POWER COST TO SELLING PRICE

Product	Fuel and Power Cost as Percentage of Selling Price of Product
Sulphuric acid (chamber process)	2.6
Sulphuric acid (contact process)	3.8
Acetic acid (acetate of lime)	1.9
Aluminum sulphate	6.5
Trisodium phosphate	5.9
Nitric acid (Ammonia oxidation)	4 0
Soda ash (Ammonia-soda)	10 3
Ultramarine blue	7.2
Caustic soda (Lime-soda)	8 2
Caustic soda (Electrolytic)	45 2

These data show clearly the importance of fuel and power cost in an electrochemical process as compared with the general run of inorganic processes.

The importance of fuel and power cost can be shown in another way. For example, sodium metal sells for 19 cts. per pound and requires 7.2 kw.-hr. per pound. With a power rate of 5 mills per kw.-hr., the power cost would be 3.6 cts., or 19 per cent of the price of sodium. However, with a power rate of 1 ct. per kw.-hr., the power cost would be 7.2 cts. per pound, or 38 per cent of the price.

Taking another example, liquid anhydrous ammonia produced by the water-gas synthesis method requires about 4 tons of coal

[1] Data from *Chem. Met. Eng.*, **39**, 2–3 (1932).

and 2,000 kw.-hr. of power per ton of product. The selling price in tank cars is about $80 per ton at the factory. With coal at $2.00 a ton and power at 6 mills per kilowatt-hour, the combined cost of fuel and power would be $20 per ton of product, or 25 per cent of the selling price. However, with coal at $5.00 a ton and power at 1 ct. per kilowatt-hour, the combined cost of fuel and power would be $40 per ton, or 50 per cent of the selling price.

According to Mantell,[1] electrochemical industry comprises about one-tenth of all chemical industry, in terms of dollar volume of production. He points out, also, that the power requirements within the major electrochemical operations vary from 12 kw.-hr. per pound for aluminum metal to 0.22 kw.-hr. per pound for white lead. For caustic soda-chlorine, the requirement is 1.5 kw.-hr. per pound of total product.

Many pulp and paper mills, which are among the largest consumers of power, are identified with hydroelectric developments, a complementary advantage being an abundant supply of clean, fresh water. Portland cement, glass and clay products plants require large quantities of fuel for process heating, and in these industries, a source of coal, oil, or gas close to the natural mineral raw materials constitutes an immense advantage.

Labor Supply.—In general, the labor factor is important in proportion to the skill required and to the number of workers required. Chemical industries, as a whole, employ a smaller proportion of skilled artisans than do the mechanical-process industries; consequently, the location of a plant with respect to labor supply rarely is the major consideration.

As time goes on, manual skill should be relatively less important in every branch of chemical industry. Continuous or semicontinuous processes, automatically controlled, will more fully take the place of intermittent batch processes. Manual skill and rule-of-thumb operation will continue to be supplanted by machines and instruments of control. By the same token, each worker will become responsible for a larger investment in plant and a larger output. This being the case, his rewards are likely eventually to increase.

Since isolation or an unattractive environment characterizes many otherwise suitable plant sites, particular stress should be placed on adequate housing facilities with the improvements

[1] *Chem. Markets*, **31**, 329 (1932).

necessary for comfortable living. Although skill in the manual arts is not an outstanding requirement for chemical-plant labor, thorough familiarity with process routines and control is absolutely essential, and it is desirable to attract and hold an intelligent and responsible type of worker.

Transportation Facilities.—Closely related to the factors of raw-material supply and market for finished products, is that of transportation. In such industries as iron smelting, lime, cement, clay products, fertilizer, heavy chemicals, petroleum refining, sugar refining, and pulp and paper, freight on both the raw materials and finished products is so considerable that it may be a controlling factor in market determination. Low bulk value is a characteristic of chemical raw materials and of many of the finished products as well.

As a rule, the highly developed transportation facilities are near large cities that occupy seaboard or waterway positions. In such a location, there is a choice between water and rail shipping. The seaboard location is particularly advantageous, should it become desirable at any time to enter the export market or to utilize imported raw materials. Hence, it is not surprising to find large centers of chemical industry near cities that combine the advantages of both rail and water transportation. Boston, Providence, Brooklyn, Port Newark, Bayonne, Buffalo, Cleveland, Chicago, Philadelphia, Wilmington, Baltimore, Norfolk, and San Francisco are examples.

Thus, low-cost transportation of raw materials to a rich local-market area was the principal factor in locating an iron-ore smelting operation near Boston, on the north shore of the Mystic River, in Everett, Mass.

Before the smelter was erected, the river channel was dredged sufficiently to pass ocean freighters as large as 10,000 tons displacement. Connections were also made with the railroad. In this location, iron ore can be obtained by ocean freight from such sources as Nova Scotia, Algeria, Sweden, and Cuba. The limestone is shipped by water from Rockland, Me., and the coke is obtained from neighboring coke ovens.

Normal consumption of pig iron within the six New England states is roughly 500,000 tons a year, or sufficient to take the output of several blast furnaces. With reasonably low operating costs, the freight differentials between the Everett smelter and

the smelters in Buffalo, Pittsburgh, and other large producing areas are said to be sufficient to insure profitable operation.

Relation to Other Industries.—Possible purchase of waste or surplus material from near-by industry should not be overlooked. Similar consideration should be given the disposal of such material from the proposed plant.

A few examples of technical interrelations that have affected choice of plant location may be cited: A plant to manufacture synthetic ethyl alcohol was located adjacent to an oil refinery, in order to be assured of an ample supply of low-cost gas, rich in olefins. Several plants to manufacture synthetic ammonia have been located adjacent to electrolytic caustic-chlorine plants in order to utilize the by-product hydrogen. A plant to manufacture solid carbon dioxide was located adjacent to a soda-ash plant. In this case, the low cost of the gas offset the relatively high freight to large centers of consumption. A gelatin plant in New England was located centrally with respect to a number of tanneries from which it purchases hide trimmings. A plant to manufacture synthetic ammonia and synthetic nitrate of soda was located on tidewater and in such position that it could (1) receive soda ash by water; (2) ship nitrate of soda by water to coastal points, as well as abroad; (3) ship liquid ammonia by rail to the fertilizer and industrial centers of the East, at a reasonably low average freight.

Fume and waste disposal may be a critical problem. Damage to property or other offense to the community is a possibility that should be foreseen and avoided, either through proper location, or by precautionary measures of plant design and operation. The discharge of sulphurous gases and dusts by smelters and the pollution of natural streams by paper-mill wastes, tannery wastes, and dyestuff wastes are a few of the common nuisances that have caused much litigation and expense. The views of Eddy[1] on the relation of industrial wastes to plant location are to the point:

Expenditures of $100,000 or $200,000 for wastes treatment plants and of $25,000 to $40,000 annually for the operation of such plants are becoming more and more frequent. Capitalizing the annual expenditure of $25,000 at 5 per cent and adding $100,000 for construction cost, making no allowance for depreciation, it appears that the industry might

[1] "Industrial Wastes Disposal," *Chem. Met. Eng.*, **17**, 32 (1917).

have expended as much as $600,000 in procuring a site which would not have entailed the necessity of wastes treatment.

The selection of a suitable site for an industry producing large quantities of wastes is a matter of much importance. Even though conditions at the outset appear to be favorable, they may be materially altered by establishment of new industries downstream or by an increase in riparian population below the plant.

Capital Requirements.—As fixed charges on a plant are directly proportional to the capital investment, plant location may have considerable bearing on the cost of production. The total capital investment includes the cost of all land, buildings, improvements, equipment, and service facilities necessary for regular production. Once the approximate geographical location has been determined, the actual site must be selected. On the one hand, there is the cheap but unimproved land of the country site as contrasted with more expensive land near cities. The more costly urban site, however, may be justified, in view of such improvements as power, gas, water, and sewer connections and highway development. Police and fire protection, also, are to be considered. It is conceivable that a plant located in undeveloped territory would, in the long run, cost much more than if a more expensive urban site had been selected. The cost of buildings will vary with the cost of materials and labor at the factory site and also with local building codes and ordinances, which govern the type of construction, storage of flammable materials, fume and smoke control, and disposal of wastes.

Free land is an inducement that may lead to false economy, since other factors tend to be overlooked, says Kelsey:

Any number of localities are seeking new factories and offer many attractive inducements. Frequently, these inducements include a free tract of land in the section set aside for plant development. The industry moves in, becomes established, starts manufacture of its products. Then, the community wakes up to the fact that instead of having an asset it has a liability, for the reason that the fumes, dust, or odors arising from the manufacturing processes become obnoxious to the people of the community and they sometimes declare them a nuisance, which results in lost production and thus creates an industrial waste.

Location Factors Quantitatively Determined.—In summarizing the factors influencing the location of plants, it is evident that

these factors have no fixed relative importance. In one example, one factor only may control; in another, four or five factors may bear on the final decision. Hence, in every problem of this

TABLE IV.—FACTORS DETERMINING LOCATION OF NICKEL REFINERY AND ROLLING MILL

Factors	Relative weight on scale of 1000	Important considerations
Labor	250	Skilled or common; supply; rates; strikes.
Fuels (for metallurgical use and power generation).	330	Cost and quality; oil; producer gas; natural gas; coal; coke.
Power	100	Public-service electric supply; costs; service.
Living conditions	100	Housing; cost of living; sanitation and health.
Climate	50	Minimum, maximum and average temperatures; average snowfall; average rainfall.
Supplies	60	Sources and costs; matte; refractories; rolls, castings and mill spares; sheet; bars; charcoal; electrodes; lubricating oils; general stores.
Transportation (railroads and water).	50	Distribution of products; domestic and export shipping; Monel and nickel shot; pig; sheet, wire, rod, forging.
Water supply	10	Service costs; quality.
Taxes and laws	20	State; local ordinances.
Selection of site	10	Railroad connections; character of ground for building and equipment foundations; drainage and flood conditions; accessibility for labor; grading and facilities for slag disposal; provision for expansion of works.
Construction costs	20	Labor; materials; supplies.

nature it is necessary to analyze thoroughly all the factors, in order to find the optimum location. How such an analysis is made is illustrated by McBride.[1]

[1] *Chem. Met. Eng.*, **29**, 745 (1923).

In planning a new refinery and rolling mill, a committee of the International Nickel Company investigated many locations in the industrial districts from the Great Lakes southward as far as Tennessee. Economic factors were investigated in detail to determine the relative suitability of those locations which on preliminary investigation looked promising. The factors considered by the company's engineers, as well as the relative weight assigned to each factor, are shown in Table IV. Examination of this table shows that availability of labor, fuels, and power were the principal considerations, having a combined weight of 680 points on a scale of 1,000 points. McBride says:

The availability in the neighborhood of Huntington of English-speaking Americans who have a good reputation in the diversified industries of that territory was an important factor in favor of this location. Because a majority of these workers is accustomed to own their homes and demands good living conditions, the labor turnover in such a plant can be expected to be small. Experience of the company thus far indicates that it is not an unreasonable expectation.

A plentiful supply of natural gas and the certainty of indefinite supplies of good quality, low-sulphur bituminous coal, to replace gas and oil when this necessity arises, insure low fuel cost for the industry. The present and prospective future power development of hydroelectric stations also was strongly in favor of this location.

CHAPTER VI

PLANT DESIGN

Plant design comprises the arrangement of (1) storage facilities, (2) material-handling equipment, and (3) process equipment in proper sequence and coordination and with regard for such other factors as future expansion, economical distribution of steam and power, hazards of fire, explosion, fumes, and leaks, and the health and welfare of workers.

As plant design is the subject of a separate book in the Chemical Engineering Series ("Chemical Plant Design," by F. C. Vilbrandt), hardly more than elementary treatment is justified here. The purpose of this chapter is to emphasize the relation between the economic and technical considerations of design, including a study of fundamental principles.

DEVELOPING THE FUNDAMENTAL DESIGN[1]

In establishing a method for making plant layouts, it is helpful to apply schematic diagrams to illustrate the underlying principles and upon these diagrams to build the plant design, just as a machine designer builds his functioning machine upon the skeleton of a kinematic diagram.

Developing the Schematic Diagrams.—Figure 6 is a schematic diagram of the simplest possible operation. It shows a single piece of production equipment, or machine, as it will hereinafter be termed, within a suitable inclosure. The process is so carried on that a single material is brought from outside, dumped into this machine, and the finished product removed immediately. There is no storage of raw material or finished product. Examples occur regularly in operations such as drying, mixing, and the simpler chemical transformations due to heat alone.

In Fig. 7 the problem is a little more complicated. Two materials are processed in the machine, but no storage is provided, and both the finished product and the waste are removed

[1] Condensed slightly from *Chem. Met. Eng.*, **32**, 494, the text and diagrams being reproduced by courtesy of Crosby Field.

immediately. Under most conditions a plant must have some storage facilities; and the simplest operation, extended to include some storage, is shown in Fig. 8. Note how the inclusion of even a small amount of storage space vastly extends the building. This fact will be noted from time to time as this study progresses.

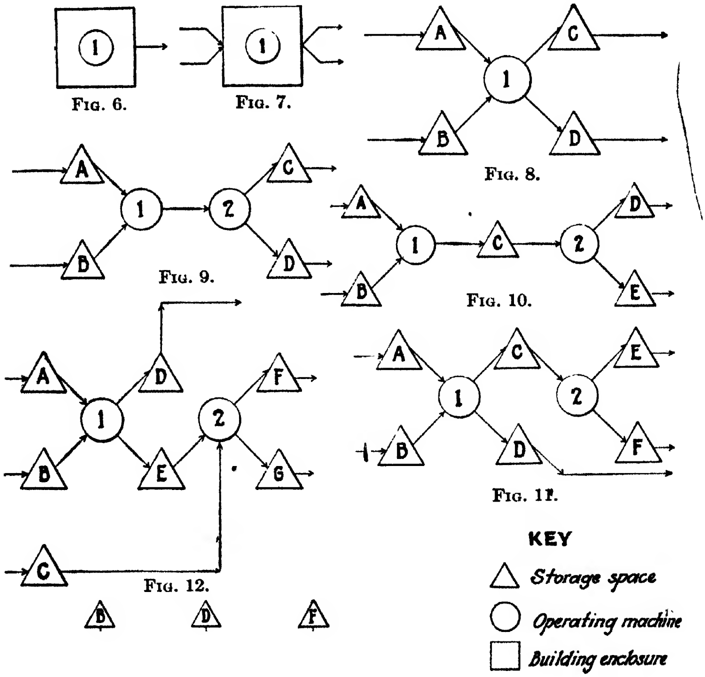

Fig. 13.

Figs. 6 to 13.—Elementary development of plant layout.
This development, which is outlined in the accompanying text, illustrates the relationship between storage space and operating machines.

In Fig. 9 one more step is shown, and there are two machines that operate upon the same material, so arranged that no storage space is necessary between the operations. It is seldom advantageous to operate in this fashion, therefore, the two operations will be extended as in Fig. 10, in which a storage space for semi-finished products *C* is included between machines 1 and 2. In

most chemical plants, however, the product from machine 1 is in two parts, one of which can immediately be used or sold, and the

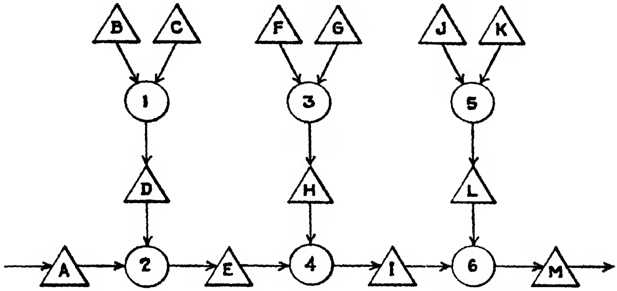

FIG. 14.—A diagram typical of many chemical plants.
Two directions of flow are shown in this diagram. Materials processed in the subprocessing lines (vertical) join the main process line (horizontal) at right angles.

other must undergo further processing in machine 2. The plant then takes on the general shape of Fig. 11. Generally, however, it is necessary in machine 2 to add something to the material from

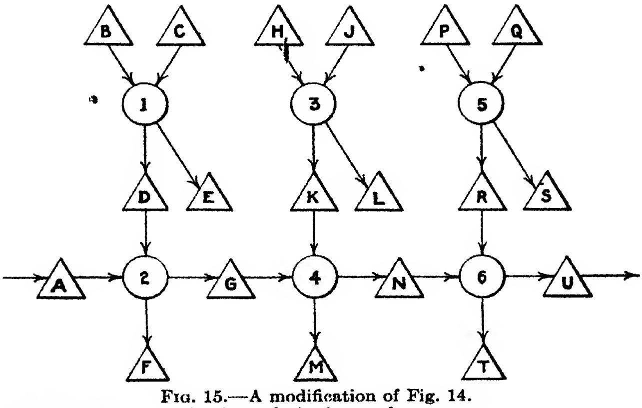

FIG. 15.—A modification of Fig. 14.
In this diagram, provision is made for by-product storage.

machine 1, and under these circumstances the plant takes the form of Fig. 12.

With a plant of three machines, however, it is necessary to follow the general arrangement shown in Fig. 13, wherein there is

sufficient storage for the raw material A and the intermediates C and E for machines, 1, 2, and 3 respectively. Storage for the finished product G is also provided in this typical chemical plant. Rarely, however, can raw material, such as B, D and F, in Fig. 13, be added directly to their machines, but instead it must undergo some preliminary processing. As a consequence, the plant is modified as shown in Fig. 14, wherein two well-defined lines of flow for material are apparent.

Figure 14 is typical of processes in many chemical plants and also of other operations, such as automobile assembly, wherein the main frame travels in one direction, and as it progresses, sub-

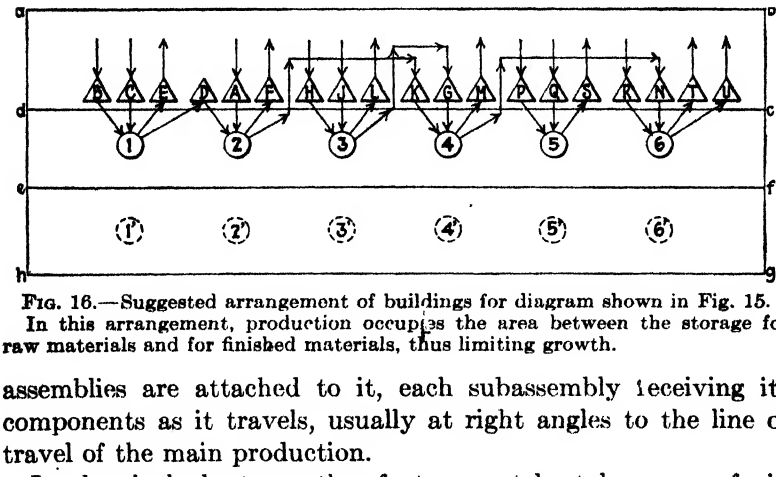

FIG. 16.—Suggested arrangement of buildings for diagram shown in Fig. 15. In this arrangement, production occupies the area between the storage for raw materials and for finished materials, thus limiting growth.

assemblies are attached to it, each subassembly receiving its components as it travels, usually at right angles to the line of travel of the main production.

In chemical plants another factor must be taken care of—in nearly every reaction of the main product, one or more by-products of more or less value are obtained. Figure 15 shows a plant with the necessary storages E, F, L, M, S, and T to accommodate such by-products.

Allocation of Space to Storage and Equipment.—By this time, not only is the addition of extra equipment difficult, but an appreciable amount of space is wasted, as there is no planned line of demarcation between the storage facilities and the manufacturing space. This results in duplication of space for each and an additional amount placed unsuitably for either. One method of solving this problem is to have a main storage space for raw materials run roughly at right angles to the main line of process flow, and a storage space for finished products parallel to this

first storage, but on the other side of the machines. This is shown in Fig. 16, wherein all the raw materials and intermediates have been allocated to the storage space *abcd*, the machines to the space *cdef* and the finished products to the space *efgh*. Although the total space required by this layout is obviously less than the space required by the previous figure, there are two decided disadvantages in the scheme. First, there is difficulty of installing additional equipment should increased production be desired; and second, the storage spaces cannot be used interchangeably.

There are many advantages in being able conveniently to use the same storage space for finished products as for raw materials. Such instances will come to the mind of every plant operator. In general, the causes are transportation difficulties, sudden decreases in orders, or other temporary cessation or sudden lessening of shipments, causing the plant to store a large amount of finished product although it may, perhaps, not receive its full quota of raw material. Under such conditions it is necessary to use the raw material on hand and take the space thus released for storage of finished products. It should be noted in this respect that it is not easy to add equipment simply by utilizing the space *efgh*, because it is usually preferable to have machines doing the same work placed side by side rather than in line when looking along the line of flow; and, if the maximum economy is to be achieved, it is desirable to reduce the capital invested, particularly for property used only indirectly in production. This can be accomplished by making a distinction between types of building for manufacture and for storage.

These changes are taken care of in Fig. 17, in which there is one storage space and one manufacturing space, each capable of extension in at least two directions without conflict with each other. It will be noted that all raw materials are stored in *abcd* and the manufacturing equipment placed in *cdef*. The raw materials are stored most conveniently near their machine, as shown: *B* and *C* for machine 1, *A* for machine 2, *H* and *J* for machine 3, *G* for machine 4, *P* and *Q* for machine 5, and *R* for machine 6. Also, the intermediate material *D* made in machine 1 is stored with the raw materials and nearest to machine 2 where it is to be used. Similarly, *K* made in machine 3 for use in machine 4 and *N* made in machine 4 for use in machine 6 are each stored near the machine in which they are to be used. It is

assumed, in making this sketch, that each machine produces some product to be sold without further processing, and storage space for these products is shown at *E*, *F*, *L*, *M*, *S*, *T* and *U*, respectively.

Providing for Expansion.—Should it be necessary to increase the production from this plant, all that need be done is to install the machines shown in *efgh*, an extension of the manufacturing department. In this connection, however, experience shows that, due either to fluctuations in demand or improvements in

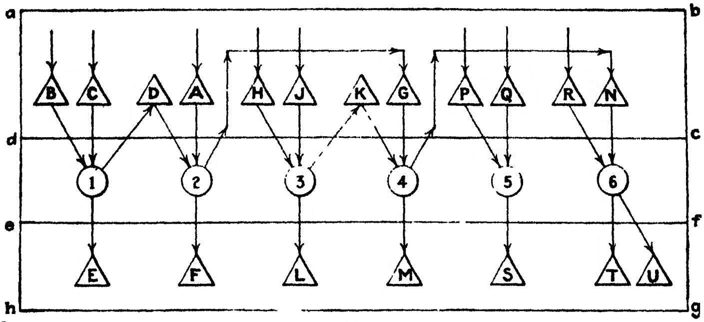

FIG. 17.—An improvement over the arrangement shown in Fig. 16. Here the storage for both raw and finished materials is concentrated on one side of the manufacturing building, thus allowing unlimited growth of storage and production facilities.

processes, it is rarely necessary to increase in its entirety any existing individual plant. Instead, more equipment of a certain type is added where the "neck of the bottle" is found. This would be difficult to arrange in the previous layouts, but in Fig. 17 it is easily accomplished. The layout then becomes that in Fig. 18, in which is shown a plant wherein three machines similar to machine 1 are needed, two of machine 2, two of machine 3, one of machine 4, and three of machine 5. When the machines are extremely large, the areas can be divided again into sections by means of lanes or walls at right angles to those above noted, so that the entire area is divided into squares. The final shape will give a storage space *abcd*, and a manufacturing outline *cdjlmn-pqrkc*. This will give the outline of the buildings or groups of buildings necessary. At any later time, it will be possible to build up the space *mnpqrl* and to extend the fronts *jk*, *aj*, *bk*, or *ab*.

Applying the Diagrams to Actual Problems.—Having made the series of kinematic diagrams upon which to base plant growth, (Figs. 6 to 18 inclusive), it becomes possible to apply these fundamentals. Many more or less simple applications at once come to mind. In order, however, to make a real test, this philosophy should be applied to a large plant which makes a great variety of products by many different processes requiring a miscellany of equipment and a large number of buildings.

In applying the diagrams, which means simply extending Fig. 18, a starting point is necessary. The best location for

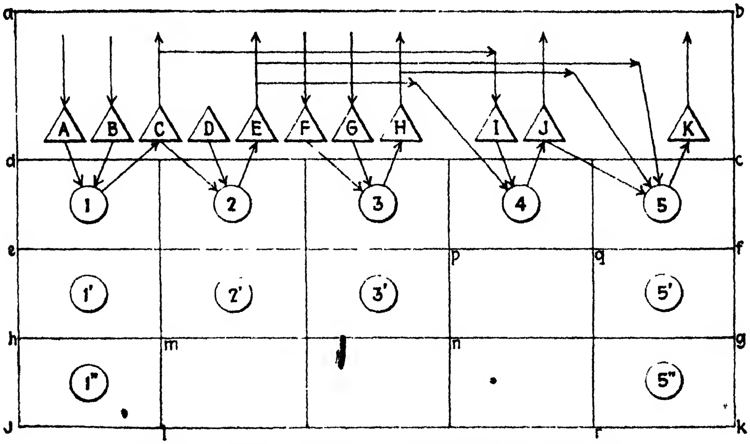

FIG. 18.—A modification of the diagram in Fig. 17

As few plants grow equally in all departments, this is a practical arrangement for most industries.

an operation of this size is a river bank along which docks and rail spurs can be built, which will supply water to the plant, and which at a downstream point will take the effluent.

Applying the diagram (Fig. 18) first to the land, a storage area *abcd* and a manufacturing area *dcue* can be laid out as in Fig. 19. Because of the size of the plant, the kinematic diagram next can be applied to the buildings, considering each as a machine. From a manufacturing viewpoint, each comprises a group of similar machines.

In order to get the maximum use of the storage space, and at the same time have each raw material or intermediate nearest its point of consumption, the storage area *abcd* should be entirely covered by a single building of dimensions determined by the

method given further on, having its long axis at right angles to the axes of the manufacturing (or, more strictly, operating) buildings.

Essential Factors in the Layout.—The three factors necessary for the general plan of any plant are: First, a starting point or location; second, a kinematic diagram or directional factor; and, third, a statement of the amount of space needed for the various storages and operations, which may be called the quantitative

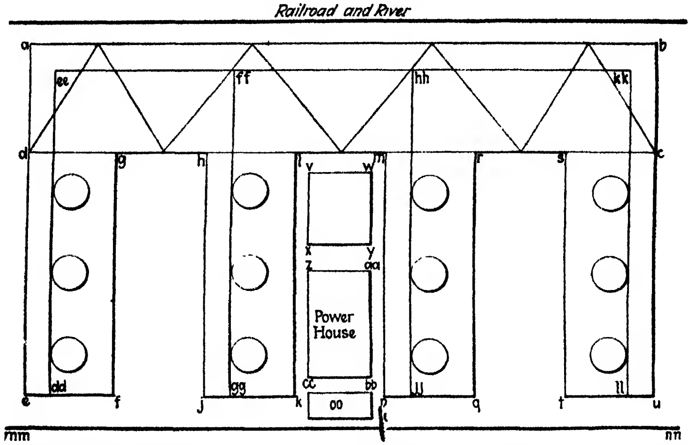

FIG. 19.—Diagrammatic representation of design principles in an actual plant. Here the outlines of the buildings are shown, and the lines of material flow appear.

factor. Combining these gives the vector diagram upon which to base the plant layout.

From known or estimated amounts of space it is, therefore, possible to obtain the proper allocations and, subsequently, the area of each building required. The operating buildings should be suitable to the operations carried on within them, of convenient width, and as long as is necessary to give the needed area. The storage building should be as long as is necessary to extend the full width of all the other buildings and the spaces between them and wide enough to give the required area. Figure 19 shows four operating buildings, *defg*, *hjkl*, *mpqr*, and *stuc*, with sufficient space for light and passage between them as shown by the space *fghj*, *klmp*, and *qrst*.

These buildings may have any height or floor levels desired. It should be noted however, that great economies can be effected

in multi-story buildings by concentrating in the storage building all elevating machinery, particularly that used for several products, and arranging for horizontal conveying to and from the operating buildings on two one-way levels, on the top story from storage to operating building by way of a bridge at that level, the return being on the ground floor. All vertical movement of material in process in operating buildings is downward, *via* chutes, pipes, and the like. The intermediate materials are stored in the storage building at any level and are brought to the top story for transportation to any building for processing. This permits a full utilization and easy control of all elevating equipment and will be found to reduce the initial installation cost as well as the operating expense of the elevators and also the irritation and expense incident on breakdown. The warehouse itself should be provided with the most suitable horizontal conveying apparatus, which can better be afforded because of the high utilization factor of such equipment. Conveyors in the warehouse are indicated by line *ee-kk* and those connecting to the operating buildings by *ee-dd*, *ff-gg*, *hh-jj*, and *kk-ll*.

It may be assumed that a product *C* is made in the group of machines 1 of Fig. 18 which are located in building *defg* of Fig. 19, using raw materials *A* and *B*. It may be assumed, further, that machines 1 can best be worked on three levels, so that the building has three stories. *A* is stored on the ground floor of *abcd* because of its weight and bulk, whereas *B* is stored on the second floor. There is a bridge between warehouse and operating building at the third story. Because of considerations to be mentioned, the transportation selected for this operation is electric industrial tractors and trailers. It then follows that the course traversed by the materials is: *A* is loaded on trailers on the ground floor, the trailers are pushed manually or by tractor to the elevator, carried by it to the third floor of the warehouse, thence by tractor over the bridge into the third floor of *defg* and into the machines. Similarly, *B* is carried from the second floor to the third, over the bridge, and to the machines. *A* and *B*, as materials in process, work down in the machines to the first floor, whence as *C* they are carried back to the warehouse and stored on any convenient floor, preferably where they are easy of access to the transportation system feeding *D* to machines 2 and 2′, considered as a group placed in building *hjkl*.

The remainder of the basic diagram of Fig. 18 can be applied to Fig. 19, in which case the concentration of transportation facilities in the warehouse must be remembered.

Selection of Material-handling Equipment.—There are two general classes of conveyors, which can be called the "continuous" and the "unit" or "batch" type. Selection of the proper class is a difficult problem, as a multiplicity of factors must be considered. One of the most frequent errors is the installation of a continuous conveyor when a much cheaper batch conveyor would have done as well, the result being only a few minutes' daily use of the expensive continuous machine.

The following factors are most important in selecting the proper conveying method:

1. Nature of the material handled.
2. Quantity handled per unit of working time per unit of distance conveyed; *i.e.*, the traffic-density factor.
3. Nature of the loading location; *e.g.*, the warehouse pile.
4. Nature of the destination location; *e.g.*, the feed mechanism to the machines.
5. Vertical and horizontal components of the path traveled.
6. Number of branch paths traveled.

It is obvious that the nature of the material has a great influence upon the conveying system, as, for example, liquids can best be transported in pipes, and corrosive liquids require special protective materials or devices for carriers. The effect of the traffic-density factor is not at first so apparent, but in general it has only a certain range in which it does not require a change in the selection as first determined by the nature of the material. Thus, water is usually transported in pipes, but when only a little is used per unit of time and the distance is great, a tank wagon may be used, that is, a change is made from a continuous to a batch system. Conversely, for a small production, a solid material is transported in batches, and when the production increases so that the number of batches becomes large, a continuous conveyor is substituted.

Locating the Power House.—After all the operating machines and buildings have been located, two important services requiring buildings remain: the maintenance building containing the machine, carpenter, forge, and other shops; and the power house. The power house should be placed as centrally as possible,

as shown by *z-aa-bb-cc* in Fig. 19. Its services are conveyed continuously in pipes or wires, arranged in the form of a large rectangle or loop passing along the edges of the operating buildings with the services to the individual buildings connected to two of the main headers of the loop. This permits cutting out any machine or group of machines, with their power feeders, for repairs and yet maintaining the services on either side. Because of supervisory and other close contact with the power house, the maintenance shops can well be located adjacent, as shown in *vwyx* in Fig. 19. When the traffic justifies, an additional conveying line *mm-nn*, for taking machines and parts to and from the various units, may be installed. This may be combined with the railroad spur feeding the coal pile *oo*.

Layout of a Large Plant.—The extension of Figs. 18 and 19 to include what is undoubtedly one of the most complex problems of modern chemical manufacture, and the modification in the general plan made desirable by the particular conditions of the problem, are shown in Fig. 20.

The warehouse and manufacturing areas are laid out on the same general plan as that followed in Fig. 19, multiplying the rails along the wharf and providing a gantry crane to take care of the large amount of material handled. In examining the materials, several are noted that are explosive, or that in the process of manufacture become an explosion hazard. These form only a small proportion of the total, and, consequently, instead of designing the entire plant with reference to these explosives, the hazards are isolated at one end of the plant in a "danger line."

Another exception to the general plan is found. One large group of products is liquid throughout the manufacturing operations. These have been segregated in a "liquid line."

A third exception occurs in the fact that most of the finished products require mixing. Great economies of apparatus and space are effected by concentrating these mixing operations, and they are placed as an addition to the finished-products section of the warehouse.

A final exception is the placing of the pumping station well upstream, to take advantage of the fresh, clean water supply.

How the Plant Operates.—All the other groups of equipment are laid out and housed as in Fig. 19. The raw material, arriving

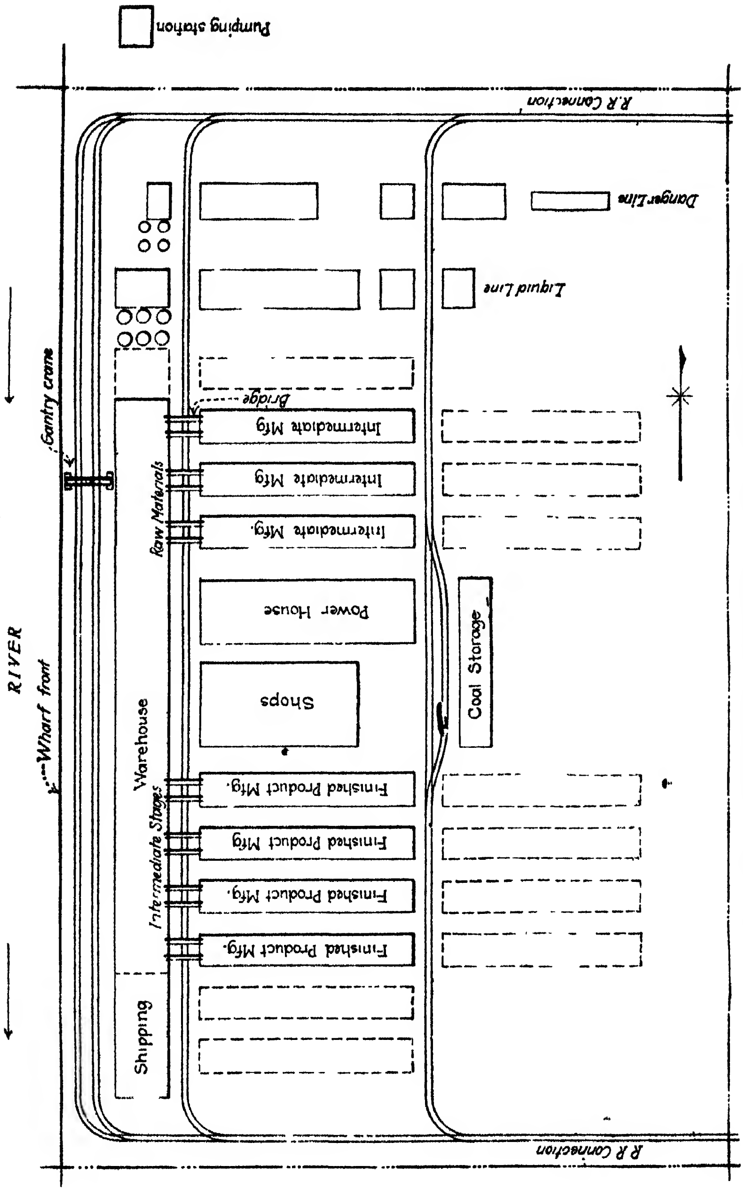

FIG. 20.—A plant layout developed from the preceding diagrams. Here are shown the space allotments to the production, storage, and transportation functions.

by boat, train, or truck, is brought into the warehouse through the door nearest to being directly opposite the building in which it is to be used first. It is stored in any convenient place, and then transported to the point of consumption by the selected conveying means. In the particular case assumed, batch movement of solids in industrial trucks is indicated. The raw material is then picked up by an industrial truck, with or without trailers, and carried on an elevator to the upper story on the same level as its point of use in the operating building (normally the top story), whence it crosses the "north" (see Fig. 20) bridge to the operating building. The truck unloads at the machine, then continues on its way to the nearest cross gallery or cross aisle, where it crosses to the other side of the building and returns to the warehouse by the "south" bridge, thus providing one-way traffic. Industrial trucks also pick up the finished product from the machines on the ground floor and carry it into the warehouse for temporary storage or for elevation and subsequent delivery to another operating building. This method of handling is repeated until the final product is carried to the "south" end of the warehouse for packing and shipping.

The industrial truck is supplemented when necessary by other conveying systems. All elevators are placed in the warehouse for concentration of vertical traffic, thus making maximum use of each.

Machinery and equipment are brought into the plant on the railway track on the "east" of the operating buildings and are lifted by the building crane and carried by it to position. Machinery requiring major repairs is carried by the crane in the reverse direction and placed on a flat car on the "east" track, to be carried to the maintenance shops, where the shop crane unloads it. The yard of the shops provides storage for such major repair parts and machinery replacements as are needed with any frequency.

In the problem upon which Fig. 20 is based, this scheme requires half the ground area of any other, affords a minimum of handling, and utilizes mechanical means for all handling. Extension of operating buildings is provided to either the "south" or the "north" by extension of the warehouse and the addition of new buildings as shown in the figure by the broken outlines; or, if the new operating departments are closely allied to those

already existing, additional buildings may be added to the "east" of the present, across the track.

In a plant of this size, construction and repair activities are of no small magnitude. The scheme provides a free to-and-fro movement from the eastern track for materials connected with these activities and such movement conflicts in no way with the free movement of production materials to and from the western track. The power plant and maintenance shops are centrally located, as was brought out in the discussion of Fig. 19.

OTHER ASPECTS OF PLANT DESIGN

One of the first steps in plant design is the tabulation and correlation of the various processes of manufacture. For example, in dyestuffs manufacture, the common unit operations are the mixing and heating of liquids, liquids and gases, or liquids and solids; the evaporation, crystallization, and distillation of the resulting solution; followed by filtering, drying, and grinding. The raw materials are benzol, toluol, xylol, phenol, naphthalene, anthracene, and solvent naphtha. From these raw materials are made such intermediates as beta-naphthol, aniline oil, and alizarin. The intermediate products and the finished dyes are made according to such processes as sulphonation, chlorination, nitration, and reduction. These primary processes are then followed by fusion with caustic soda and caustic potash in order to make a low-melting, soluble salt, and to neutralize any free acid that may be present.

When the nature of the processes and the materials to be handled has been determined, a flow sheet is constructed. This will show the kinds and quantities of raw material entering the process; the sequence of manufacturing processes; the paths by which finished products, by-products, and wastes emerge from the process; the temperatures, pressures, and compositions of materials in process; and all additions or removals of heat and power. When the quantities of material handled at each stage of the process are known, provision for handling such materials can be made.

Material Handling a Major Consideration.—The importance of designing chemical plants with reference to efficient material handling cannot be overemphasized. If materials are received in large carload lots or by ship, the types of material-handling equip-

ment found practicable in other industries should be adopted. The iron and steel industry is an example of highly developed material-handling practices. Marshall[1] points out the marked tendency for machinery developed primarily for the metallurgical industries to find application in the chemical industries. This includes such equipment as belt conveyors, gantry cranes, and grab buckets. Fundamentally, no differences exist in large-scale handling methods among the various industries, and the chemical engineer will do well to apply the equipment already developed in other industries.

Material handling is in itself a highly specialized engineering branch; therefore, in the preliminary stage of design, it is wise to consult competent industrial engineers as to the selection of equipment for handling the various gaseous, liquid, and solid materials. In considering these problems, close cooperation with the plant chemical engineers is essential, as the selection of materials of construction is so important. In the mechanical process industries, such common materials as iron, steel, and wood can be used with no fear of trouble; but in the chemical industries, special materials for each equipment are the rule instead of the exception. The importance of materials of construction is attested by the great variety of special materials, such as glass, fused quartz, acid-resisting and heat-resisting alloys, and protective coatings that have appeared on the market within recent years.

Material Handling Underlies Design.—In the so-called "heavy chemical" plants, the flow of materials is large, and every opportunity should be taken to make this flow continuous. All structures must be strong enough to carry the material-handling equipment and its load. For this reason, the weight of materials to be handled and the design of the material-handling equipment should be calculated prior to the design of the buildings. It is fundamental that in the chemical industries the buildings should be built around the process. In the petroleum-refining industry, for example, the buildings are merely accessory to the process equipment. Common practice is to construct storage tanks, towers, stills, and cracking equipment without any housing except for the pumps and control apparatus.

[1] "Lessons for Chemical Engineers in Other Industries," *Chem. Met. Eng.*, **22**, 218 (1920).

Material-handling problems can be classified as follows:

1. Movement of raw materials from the railroad siding, ship, motor truck, or tank car to the raw-material storage, or other points where production starts.
2. Movement of materials in process from one part of the plant to another.
3. Movement of the finished product to warehouse or shipping point.

Handling Raw Materials.—The method of handling raw materials will depend largely on the type of package in which they are received. Hatman[1] has classified the usual possibilities as follows:

1. Bulk liquids in tank cars or tank ships.
2. Bulk dry materials in cars or ships.
3. Bags in cars, motor trucks, or ships.
4. Barrels in cars, motor trucks, or ships.
5. Drums of solids or liquids in cars or ships.

Liquids received in bulk in tank cars can be drawn off by gravity, or by pumps, as with oils; or compressed air may be used, as is common practice with acids and other corrosive liquids. No trouble should be experienced in unloading liquids from tank cars unless the liquid has high viscosity, in which case large-diameter pipe must be used in order to assure low pressure drop through the line. In cold weather, the viscosity of such materials as heavy oils or tars may be so high that a steam-jacketed discharge line is necessary.

Solid materials received in bulk are unloaded at least expense from gondola cars into track pits. Under certain conditions, the same method is applicable to box cars and motor trucks. Cranes are used almost wholly to discharge bulk materials from ships. The method should be rapid enough to avoid demurrage imposed by the common carrier. After the bulk raw material is unloaded to the track pit, wharf, or other intermediate point, it is transported to the raw-material storage. The method will depend upon the characteristics of the material and the vertical and horizontal distances through which it must be moved. Ordinarily, conveyor belts, bucket elevators, industrial railway cars, and electric or gasoline tractors equipped with trailers are gener-

[1] "Increased Production Efficiency Means Good Material Handling," *Chem. Met. Eng.*, **27**, 396 (1922).

ally applicable. When the material is in the form of a light powder, or is toxic, pneumatic conveying has special advantages that should not be overlooked. This method is, of course, applicable to heavier materials as well. Its greatest usefulness, however, is in the special fields mentioned.

Materials received in bags, barrels, or drums are best unloaded on a receiving platform, weighed, and then hauled to storage by a gasoline or electric tractor.

Interdepartmental Transportation.—The next problem is interdepartmental transportation. The important factor is the design of such equipment to synchronize fully the capacity of the various process equipment. Corrosive liquids can be elevated by air lift and made to flow through the process by gravity.

Choice of a method for transporting solid materials depends on both their condition and whether a continuous flow of material can be realized. In general, when the flow is continuous, the material can best be moved by a fixed conveyor system, such as bucket elevators and belt conveyors. Typical of this is the portland cement industry, in which the clinker, an intermediate product, is conveyed continuously on belts.

Certain industries present special problems in conveying, and these are so inextricably bound with the process that they hardly ever are recognized. For example, in pulp and paper manufacture, water is the transporting medium in which the solid material, wood pulp, is suspended. When water is not plentiful, or when there are restrictions against stream pollution, a recycling of the water should be considered.

When the movement of solid materials from process to process is intermittent, a fixed conveyor may not be indicated. As a rule, mobile electric trucks, or even hand trucks, are most useful when the processes are discontinuous. These machines are extremely flexible and can be moved from place to place as required. For continuous operation, a large proportion of the system should be fixed, although manual methods may be more economical in certain parts of a plant. Examples probably exist in which the cost of labor is greatly overbalanced by the cost of power and overhead expense inherent in fixed conveying machinery.

Transporting Finished Products.—The handling of the finished products resembles that of raw materials, except that greater care

is taken to prevent contamination. The common containers are bags, barrels, boxes, carboys, and drums. One of the most difficult situations in material handling is in the heavy chemicals industry, in which a multiplicity of products—liquid and solid and, sometimes, gaseous—are produced for a large number of consumers. When the number of products is large and the unit size of the container small, low cost in material handling requires the simplification and standardization of containers as far as practicable and provision for weighing and filling the containers automatically or semiautomatically. Another consideration is the economical transport of these packages after they have been filled. A satisfactory solution of this type of problem is described by Hatman:

> A successful solution of this problem, from the experience of one of the largest plants in the country, shows what can be done. The nature of their products made necessary a large variety of containers of different weights and sizes. Finding the hand method of movement too costly, they had a thorough study made of the possibilities. As a result, they adopted a special type of skid having a box-like receptacle mounted on it, the walls of which could be varied in height. They then standardized on containers—still various in size and shape—which would fit into these receptacles.
>
> A multiplicity of these skids was built. Lift trucks handled the skids at the plant and into cars and ships. Goods were shipped to their branches in the receptacle skids, and at those points lift trucks again did the moving. The saving effected was nine-tenths of the sum previously spent on handling.

Relation of Storage to Plant Design.—Using the explosives industry as an illustration, Kiler[1] has pointed out how storage problems relate to plant design:

> *Storage of Raw Materials.*—The size of storage will depend upon the geographic and economic location of the plant. The kind of storage will depend upon the kinds of materials to be stored. Some materials should not be stored in wooden structures, while others should not be stored in steel structures. For example, it is inadvisable to store nitrate of soda in wooden buildings. The nitrate of soda will actually impregnate the wood, weakening the structure in about the same manner as dry rot. The impregnated wood is highly combustible, and spontaneous combustion is likely to occur.

[1] "The Relation of Plant Design to Storage Facilities," *Chem. Met. Eng.*, **32**, 687, 809 (1925).

Storage of Materials in Process.—Proper storage for materials in process must be considered, especially from the geographic standpoint. With some materials, it is absolutely essential that some type of humidity control be installed; whereas with others the material may be stored in the open. We have had a peculiar example of storage of materials in process in our mixed-acid storage tanks. The mixed acid is nitric and sulphuric acids mixed to proper proportions for nitrating purposes. The nitric acid, being volatile, distills off when the tank is exposed to direct rays of the sun and remains in the tank as a gas until the tank cools off, when it condenses, forming weak nitric acid. The globules of weak acid run down the sides of the tank to the surface of the acid, where the collected weak nitric acid attacks the metal of the tank. As a precaution, we are now installing sun-shades all over all mixed-acid storage tanks to prevent this.

Storage of Finished Product.—In the explosives industry, the storage of finished product resolves itself into two points: proper distancing, and protection against the weather. Under proper distancing, we mean distance from adjacent plant buildings, from public highways, from public railroads and from buildings of adjoining property owners. Under proper protection from the elements, there should be subdivisions as to class of structure and type of material that is being stored therein.

We store commercial high explosives in brick magazines properly equipped with ventilators and sand trays where necessary and with adequate bulletproof doors. The reason for this type of construction is obvious. Black powder in kegs is stored in wooden frame buildings, galvanized iron or zinc covered.

Effect of Location on Design.—As pointed out by Kiler, location is a factor affecting the details of construction. The designer must allow for excessive rainfall, snow, ice, humidity, heat, wind, and other physical features imposed by climate. For example, a building constructed in the northern states must have ample provision for snow loading, must be provided with ice breakers on the roof, for protection against icicle formation over passageways, as well as for ample rain gutters and leaders. The same process in the southern states would indicate a different type of building construction as being most economical.

At a southern plant, provision is made for wind loads at a velocity of 65 miles per hour. Column, purlin and girt costs are increased considerably, but it has been found cheaper to take these costs than to take the risks involved in a weaker structure.

The direction of prevailing winds, likewise, should be studied so that fire doors of boilers and furnaces and doors of all chambers

where hot or finely divided materials are handled, may be placed to leeward. Wind direction may affect also the disposal of dusts and fumes, particularly if the plant is near a densely populated center.

Air temperature is important, because it affects the design of the heating system for buildings. It may affect also the design of systems for handling and storing materials, liquids especially. Thus, in extremely cold climates, pipe lines, tanks, and pumps may require extra protection. Likewise, extremes of hot weather may require refrigeration in certain processes, air conditioning in parts of the plant, or insulation of buildings and storage tanks.

Fire Hazards in Relation to Design.—Of the various industrial wastes, that from fire is probably the easiest to measure, as losses on insured property are known accurately and other losses can be estimated from experience. Recorded fires alone cause an average annual property loss of about one-quarter billion dollars, and a large portion of this loss is industrial. Richardson[1] classifies the potential causes of fire as common and special hazards. Common hazards are those present generally, and include the hazards from heating, lighting, and power systems, and accumulated rubbish. These common hazards have been studied so thoroughly by insurance companies and plant engineers that excellent preventive and combative measures have been developed.

Special Fire Hazards.—Among special hazards might be mentioned dust-laden air, mixtures of flammable gases and vapors with air, and the storage in large quantities of flammable liquids and easily ignited solid materials. Published information on common fire hazards is obtainable from the National Board of Fire Underwriters, from the National Fire Protection Association, or from engineers and architects that specialize in industrial construction.

Special hazards are problems for experienced engineers to solve, and careful investigation will be necessary before intelligent recommendations can be made. For example, the fire hazards of the petroleum refinery, hard-rubber plant, cornstarch plant, paint and varnish plant, explosives and dye plants are continually being studied with a view to systematic prevention, both through

[1] "Some Considerations on Fire Waste," *Chem. Met. Eng.*, **25**, 397 (1921).

better plant design and better operation. Such studies should include the following factors:

1. Nature of raw materials being used, that is, flammability and sensitivity to smoke and water.

2. Storage facilities for raw stock and decentralization of such stores to limit loss in the event of fire.

3. Application of the foregoing studies to materials in process and to finished products.

As emphasized by Richardson, a common fallacy is to assume that so-called fireproof construction is adequate protection against loss. This type of building may prove to be nothing but a furnace if it contains large amounts of flammable material. Decentralization of storage, segregation of processes using volatile solvents, provision of exhaust fans and collectors in dusty processes, restriction of smoking, and constant inspection of buildings, equipment, and stock are, in general, sound preventive measures.

Corrosion as a Factor in Design.—If losses from corrosion were limited simply to the value of the equipment itself, the situation would not be particularly serious. In addition, however, to the monetary loss through premature depreciation of the equipment, there are losses from frequent and costly repairs, losses of material through leakage from pipe lines, tanks, pumps, and other process equipment, the monetary equivalent of loss of production during shutdowns, and finally, loss through contamination of materials in process by the products of corrosion.

Practical Aspects of Construction.—An excellent account of various means of combating corrosion in industry has been given by Calcott.[1] For example, in building construction it is often possible to substitute or supplement various relatively inert materials of construction for steel. Among such materials are tile, concrete, brick, protected metal, transite, and wood. Steel can be imbedded in concrete or other masonry. Another preventive measure is to decrease the concentration of corrosive fumes by providing better ventilation.

In floor construction there is a wider range of materials. Concrete is usually satisfactory for neutral salt solutions or alkaline solutions. Acid-proof brick or bituminous material is

[1] "Avoiding the Effects of Corrosion on Buildings and Apparatus," *Chem. Met. Eng.*, **32**, 685 (1925).

satisfactory for acidic solutions. An important feature of floor construction, regardless of the materials used or conditions of service, is proper drainage. Frequent washing of floors with water will remove reagents, which, if allowed to remain in concentrated form, might cause considerable damage.

Materials of construction for process equipment comprise a far more serious problem. Regarding the difficulty of selecting a suitable material of construction, Calcott says:

> In selecting a suitable material for apparatus construction, the first difficulty encountered is the very limited field from which the choice must be made. If only resistance to corrosion were required, the choice would be simple, but this is complicated by the fact that the material must also have suitable mechanical or physical properties. Still more unfortunately, the materials of suitable physical properties are very likely to be entirely unsuitable chemically, and vice versa. From the point of view of strength, the ease of working, and other mechanical properties, the ordinary ferrous metals leave little to be desired, but, unfortunately, they are readily attacked by acids and, if alloyed to increase their acid resistance, usually become either unsuitable physically for structural work or highly expensive. Since, on account of corrosion, the average life of chemical apparatus is rather short, it must be constructed of relatively cheap material. In calculating this cost, of course, it should be figured as added to the price per pound of the material produced in the piece of equipment during its useful life; otherwise, the results may be distinctly misleading.

Relation of Corrosion to Hazards.—Another aspect of corrosion is that of hazards through failure of the equipment. Common illustrations of this are leakage of explosive, flammable, or toxic gases, vapors, and liquids from pipe lines, pumps, tanks, and other equipment. Whenever possible, the equipment should be designed so that in the event of failure the operator will be protected from contact with escaping material. Ample room must be allowed for inspection, and risks should be minimized by scattering the plant over as large an area as is practicable. Particularly is it essential to isolate equipment that operates at high pressure or high temperature, as under these conditions failure has relatively serious consequences.

Damage from bursting or leaking equipment can be minimized by inclosures that will retain the escaping liquid. When the material is in the form of gas or vapor, a good system of ventila-

tion will be found most effective. In the design of the equipment itself many practical details must be observed if the best results are to be realized. For example, the joining of exposed dissimilar metals is, as a rule, undesirable. Likewise, cold-working without subsequent annealing has produced disastrous effects, because of the resulting strained condition of the metal. This is particularly true of riveted work. Similarly, hot-working of metal may produce an electric couple that is sufficient to induce disastrous local corrosion. This may result from oxide inclusion in a weld, or merely from a change in the physical structure of the metal itself and in the absence of impurities. Such seemingly small details of design and construction are those to be watched with particular care—as much so as the selection of the material of construction itself.

Employee Welfare and Plant Design.—Considering that the industrial wage earner spends about a fourth of his productive life on the plant, his welfare while there is tremendously important. In certain respects, the law defines and protects the wage earner's welfare. In other respects, the management and the worker's own collective bargaining agency function in that regard. Among the physical necessities or aids to employee welfare are convenient and safe automobile parking space; ample change-house facilities, including showers; convenient toilets and drinking water; an athletic field and recreation building; adequate illumination, considering the nature of the work; adequate ventilation and heating; provision of every reasonable safeguard against hazards from machinery, dusts, fumes, poisons, explosions, fire; and first-aid and medical facilities.

Facilities for employee welfare should be designed, constructed, and maintained in accordance with the standards set for other activities of the company. If the plant designer will imagine himself in the worker's shoes, he will not go far wrong.

CHAPTER VII

UNIT OPERATION COSTS

In this chapter, approximate costs are shown for equipment and for the operation of equipment, three typical chemical engineering unit operations being used as illustrations: (1) filtration, (2) evaporation and (3) the subdivision of solids by crushing and grinding. Obviously, a complete survey of the unit operations according to such a plan is out of the question in a book of this size, the object of this incomplete survey being to outline a method of calculating unit operation costs. Any careful study of unit operation costs is bound to include questions of choice of equipment; consequently, a short description of machine characteristics is included in each section.

FILTRATION COSTS

Characteristics of Various Filters.—Appreciation of the characteristics of various filters is necessary for a determination of their relative value for a specific application. Certain essential engineering features of filter presses, leaf filters, and vacuum rotary filters are summarized in the following paragraphs. For a more comprehensive survey, reference should be made to other sources, such as Wright.[1]

Filter Presses.—Filter presses are the most widely used type of filtration equipment in the chemical process industries. Cast-iron presses are designed ordinarily for pressures up to 150 lb. per square inch, and represent most of the presses now in use, although they represent less than half the total tonnage because of relatively low capacity. Wood presses of cypress, yellow pine, and maple find considerable use with acid liquors and are built for pressures of 50 lb. per square inch.

Although filter-press construction differs in detail, the two main types are the recessed plate and the flush plate-and-frame press. In the former, the cake space is obtained by recessing the filter

[1] "Industrial Filtration," Reinhold Publishing Corporation, New York.

plate, so that a space of ½ to 1 in. is left between plates when the press is closed. In the latter, a spacing frame, ½ in. to 4 in., is inserted between the filtering plates to provide cake space. The volume of cake space is therefore more flexible in the plate-and-frame press.

The product from filter presses is delivered as a cake that is more or less firm, depending on the material, the pressure, and the filtering time. The formation of a unit cake that is fairly dry and coherent constitutes a decided advantage over other types of pressure filters. On the other hand, this type of cake can be obtained only by continuing filtration until the press is filled with solids; consequently, there are definite upper and lower limits to the cake capacity per square foot of filtering area for a definite thickness between filter plates. To meet this objection, the proper width of spacing of distance frames for a particular slurry can be determined experimentally for average conditions.

Filter presses are preferred especially for small tonnage slurries when the solid constituent is to be saved. Washing can be employed with fair satisfaction, depending considerably on the material being filtered. Filter presses have a low capital cost, and this is frequently an overwhelming advantage in small installations, or in new ventures in production. They are made in a wide variety of capacities, and the filtering units are readily replaceable. On the other hand, capacity per square foot of filtering area is lower than with pressure-leaf filters, and the labor for cleaning and reassembling is a serious objection in large installations.

Pressure-leaf Filters.—Pressure-leaf filters represent the development of the filter press with a view to reducing labor costs and increasing capacity per unit filtering area. Essentially, all the types consist of a closed steel drum or casing containing rigid filtering leaves. The slurry is pumped into the drum under pressure, and the filtrate escapes through the leaves and is piped away. In the Kelly and Sweetland filters the leaves are rigid, and in the Vallez type they are mounted on a rotating shaft.

Pressure-leaf filters are adapted primarily for clarification, particularly with hot liquids. They have high capacity and low labor requirements for filtering slurries containing only small amounts of solids. They represent a greater initial investment than the filter press, consequently are not generally employed in

small installations. Although washing can be carried out efficiently in pressure-leaf filters, they are unsuited for work when a fairly dry cake is wanted.

Vacuum Continuous Filters.—Vacuum rotary continuous filters represent a development of filtration with high capacity and continuous operation as the objectives. They consist of rotating filtering drums or disks partly immersed in the slurry. The cake is pulled onto the filter, as it passes through the bath, by suction from inside the filter, and the moisture in this cake is pulled through the filter after emergence from the slurry. If necessary, washing may be applied effectively near the top of the path of rotation, and a further drying would then follow. The cake is discharged on the downward travel by a knife, with or without the aid of compressed air. The filter cloth is protected from the knife by wires. The exact arrangement of this cycle is dependent on the type of filter and on the material.

The vacuum continuous filter is adapted admirably to granular free-filtering solids, and it operates on these with high capacity and low labor cost. The uniform cake discharge is a considerable advantage, especially when filtration is one unit in a series of continuous operations. This filter cannot generally be used with slimy precipitates, is not well adapted to liquids near the boiling point; the initial investment is high, and power is an important item of expense.

Cost of Filtration Equipment.—Equipment cost has a direct bearing on operating cost and is, therefore, one of the major considerations in the selection of filtration machinery. As the total initial investment represents the capital outlay required up to the point of productive usefulness, the cost of accessories and of installation logically is included in any cost analysis.

For purposes of comparison, the costs for different types of equipment should be expressed on a common basis. An ideal basis for filtration costs should include both the capacity and the efficiency of the machine. Capacities vary widely with the material being filtered, with the machine, and with the operating conditions. Moreover, the significance of the term "efficiency" is determined by the specific requirements made on the filter; hence, an ideal basis cannot be obtained. The most satisfactory practical *cost* basis is the square foot of filtering area, which is a good capacity factor when applied to any one machine on a

definite slurry. It should be remembered, however, that the capacity per square foot varies widely with both the material and the type of machine, and further, that this basis is not in any way related to washing efficiency, dryness of cake, and the like, all of which may determine the value of the operation. Realizing these limitations, the above basis is nevertheless convenient for presenting cost estimates. The following data have been expressed as cost per square foot of filtering area and are shown plotted against the total filtering area of the equipment.

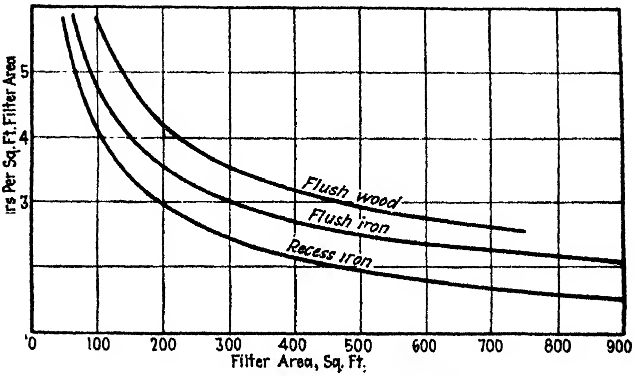

FIG. 21.—Cost of filter presses.

Cost, which, is expressed in dollars per square foot of filter area, does not include accessory equipment.

Filter Presses.—Figure 21 shows the cost of flush wooden, flush iron, and recessed iron filter presses, varying from the 12-in. laboratory press to the large 48-in. factory press. Costs are calculated for full presses, and in the flush wooden and flush iron presses the distance frames are 1½ in. thick. To obtain the cost of any filter, the cost per square foot should be multiplied by the total square feet of filtering area. For example, a flush iron press with 300 sq. ft. of filtering surface would cost (300)(3.00) = $900.

The cost of accessories and of installation will vary considerably with each specific example. For accessories (pumps and strainers) from 20 to 25 per cent on the base cost of the filter itself, and for installation (not including tanks) from 25 to 30 per cent represent fair approximations. In the foregoing example, the complete cost of the press installed would then be

$900 + (0.50)($900) = $1,350, assuming 50 per cent of the base cost for accessories and installation combined.

The cost of presses using different widths of distance frames does not vary markedly from the data of Fig. 21. The same is true when the press is only partly filled with plates. The reason for this is that the filter plates themselves form the major item of cost in the total. Table V shows the costs of the various units of the press and serves to explain these facts.

TABLE V.—COST OF FILTER PRESSES

Size (inches)	12	18	24	30	36	42
Weight empty press (pounds)	650	1,550	3,000	4,000	5,500	7,800
Weight press filled with 2-in. iron frames (pounds)	1,100	8,100	14,400	21,200	30,100	40,600
Cost of empty press	$130	$170	$230	$300	$370	$460
Area per plate, square feet, iron	1.6	3.5	6.6	10.7	16.0	22.4
Area per plate, square feet, wood	1.0	2.5	4.8	7.7	10.7	15.1
Plate capacity of one press	15	50	50	50	50	50
Cost of plates per square foot of filter area:						
Recessed, iron	$3.20	$2.10	$1.50	$1.25	$1.15	$1.07
Plate and frame, iron	$4.90	$3.30	$2.40	$1.90	$1.70	$1.70
Plate and frame, wood		$5.20	$3.33	$2.34	$2.10	$1.92

Example:

To find cost of flush iron press to give 700 sq. ft. filtering area in one 36-in. press:

$$\text{Cost} = \$370 + (700 \times 1.70) = \$1,560.$$

Pressure-leaf Filters.—The cost of filter machines of the pressure-leaf type is shown in Fig. 22. It will be seen that the cost curves are of the same type as for filter presses; that is, the cost per unit filter area decreases rapidly as the size goes up. Although the cost of filters of the press type is roughly proportional to the number of plates, and the cost of the empty press is relatively small, such is not true of pressure-leaf filters. With pressure-leaf filters, the cost of the body or shell is a relatively large item, and the cost of frames is not a controlling factor. The cost per unit filter area of pressure-leaf machines, furthermore, is dependent to a large extent upon the spacing of the frames within the body. Thus, the cost per unit filter area for 4-in. spacing of frames is from 30 to 50 per cent greater than for a 2-in. spacing.

Advantage should be taken of the smallest allowable spacing, which is governed by the cake thickness.

A suitable centrifugal liquor pump and equipment for compressed air are the usual accessories, and the cost of these should

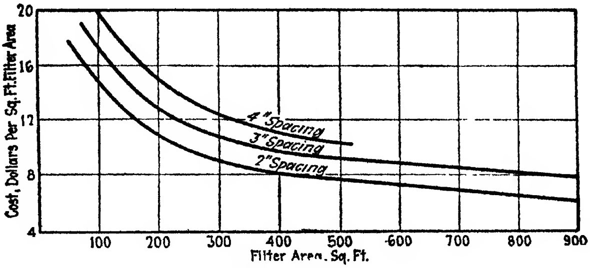

FIG. 22.—Cost of pressure-leaf filters.

Cost, which is expressed in dollars per square foot of filter area, does not include accessory equipment.

not exceed 20 per cent of the cost of the filter itself. Installation costs will vary somewhat with the amount of piping and should approximate 25 per cent of the cost of the filter.

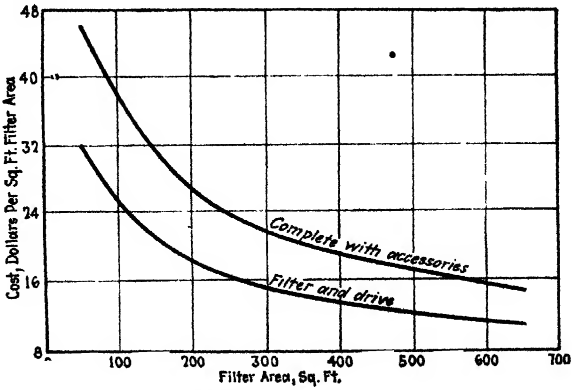

FIG. 23.—Cost of vacuum continuous filters.

Cost, which is expressed in dollars per square foot of filter area, includes drive and accessories.

Vacuum Continuous Filters.—Figure 23 shows the cost of vacuum continuous filters, both with and without accessory equipment. As considerable accessory equipment is required

for the operation of this filter, the total of these items will range from 50 per cent of the base machine cost, in the small sizes, to 30 per cent in the larger sizes.

The cost of installation is about the same as for the pressure-leaf type, or about 25 per cent of the base cost of the filter. It will be noted that the unit cost of this type of filter is many times

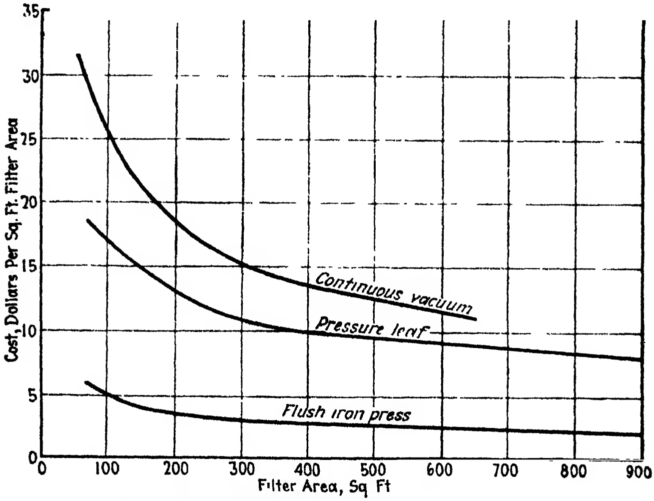

FIG. 24.—Comparative cost of filtration equipment.
Cost, which is expressed in dollars per square foot of filter area, does not include accessory equipment.

that of the filter press, and considerably more than for the pressure-leaf filters.

In Fig. 24 the base costs of the three types of filter machines are compared for the sake of convenient reference. More detailed information on each type can be had from the other curves, mentioned previously.

Cost of Filter Operation.—The important items of operating cost are as follows:

1. Interest.
2. Depreciation.
3. Power.
4. Direct labor.
5. Maintenance and supplies.

The practice of including interest is recommended when comparing the performance of different equipment, and is based on the idea that if the money were invested outside the business it

would then earn approximately that rate. A safe rule is to include interest whenever operating costs are to be compared; in other calculations it may be omitted. For example, when the more expensive filter machine is chosen, the additional investment over the cost of a cheaper type must be justified by a definite increase in the net profit on the operation, either through increased value of the product or through unmistakable economies of operation.

All charges to operation, except interest, vary with the type of equipment. In the discussion that follows, operating charges will be treated in turn under each type of filter, and illustrated by examples taken from plant practice. The total cost figures obtained in the three illustrations should not be used as a direct comparison of the three filters themselves, as the applications and service conditions vary widely.

Filter-press Operating Costs.—With regard to depreciation, no rigid rule can be stated, since filter practice varies within wide limits, even with the same type of slurry. Generally, a filter press of rugged construction will not depreciate more than 10 per cent a year when operating on neutral slurry. With care in operation, this figure may be lowered to 5 per cent. On the other hand, extremely corrosive slurries may cause 100 per cent depreciation. Under such conditions, however, a wooden press should be employed. A wooden press, even under severe conditions will stand up two or three years in filtering acid slurries. With proper care, wooden presses may remain serviceable as long as those made of iron.

Power requirements, with a typical free-filtering metallic salt, will be about 0.005 hp. for each square foot of effective press area. With compressible sludges this figure may increase enormously, on account of the high working pressures attained.

Labor requirements are fairly uniform for each type of installation. Filter presses require the most constant attendance, and this is a definite offset to their low first cost. Two men ordinarily are needed full time for two presses of medium size (24-in. presses having 200 sq. ft. of filter area each).

Aside from cloth replacement, little maintenance is required on filtration equipment. A figure of 3 to 5 per cent a year of the total initial cost of the filter is an average maintenance charge, exclusive of cloth replacement.

With filter presses, in which the cloth is continually being disturbed and scraped, a life of from 3 to 4 weeks may be expected, assuming 10-hr. daily operation and working with a sludge of precipitated metallic salt. Cotton duck or chain cloth for presswork costs about 10 cts. per square foot.

Example of Filter-press Operation.—In this example the equipment and operating specifications are as follows:

1. Two 24-in. square filter presses are used, each having 30 chambers, 1-in. frames, a filtering area of 211 sq. ft. and a total effective volume of 8.79 cu. ft.

2. The slurry is a precipitated metallic salt, the cake of which before drying contains about 40 per cent moisture, and the dry weight of which is 80 lb. per cubic foot. The cake is washed to 0.01 per cent soluble matter.

3. About 8,000 gal. of slurry is to be filtered per 8-hr. day, 300 days a year, the length of cycle being 2 hr., which includes filtering, washing, blowing with air, and cleaning the presses. Eight batches, 8.79 cu. ft. per batch, dry weight 80 lb. per cubic foot, are produced per day, equivalent to 2.81 tons of solids.

Interest.—From Fig. 21 it will be seen that a flush iron press having 211 sq. ft. of filter area will cost \$3.45 per square foot, and the cost of the two presses will be

$$(3.45)(211)(2) = \$1,456.$$

The cost of accessory equipment and installation will be 50 per cent of the base cost,

$$(1,456)(0.50) = \$728,$$

making of total investment = \$2,184.
The daily interest on the investment, at 6 per cent per year, assuming 300 working days, will be

$$\frac{(2,184)(0.06)}{(300)} = \$0.44.$$

Depreciation.—Assuming 10 per cent uniform depreciation per year on the total investment, the daily charge will be

$$\frac{(2,184)(0.10)}{(300)} \quad).73.$$

Cost of Power.—Assuming the cost of power to be 1 ct. per horsepower-hour, and the power consumption to be 0.005 hp. per square foot, the total power cost for 8 hr. will be

$$(211)(2)(0.005)(0.01)(8) = \$0.17.$$

Cost of Direct Labor.—With labor at $4 per day, the charges for two men will be

$$(4.00)(2) = \$8.00.$$

Cost of Maintenance and Supplies.—With prepared cotton duck at 11 cts. per square foot, and an expected life of 22 working days of 8 hr. each, and assuming the cloth area per press to be 260 sq. ft., the cloth cost per day will be

$$\frac{(0.11)(260)(2)}{(22)} = \$2.60.$$

Repairs and all other necessary maintenance, at 3 per cent per year, will be

$$\frac{(2,184)(0.03)}{300} = \$0.22,$$

making a total maintenance charge of $2.82.

SUMMARY OF COSTS

		Percentage Analysis
Interest	$ 0.44	3.5
Depreciation	0.73	6.0
Power	0.17	1.4
Labor	8.00	65.8
Maintenance and supplies	2.82	23.3
Daily cost	$12.16	100.0

Cost per ton of solids $\frac{\$12.16}{2.81}$ $4.33.

From the foregoing illustration, it will be seen that labor and filter cloth constitute the greater part of filter-press operating costs, being in this example almost 90 per cent of the total.

Pressure-leaf Filter Operating Costs.—The useful life of pressure-leaf filter machines is about the same as that of filter presses. This is to be expected, as the materials of construction and the slurries are practically the same with both types. An over-all depreciation of 10 per cent yearly would certainly be conservative practice in most installations. Here, again, the corrosive prop-

erties of the slurry are controlling. With care, the bodies of pressure filters should last 20 years, but the frames will have to be replaced every 5 years or so.

Power is required for operating the liquor pumps and will range from 0.005 to 0.02 hp. per square foot of filter area, depending upon the head against which the pump is working.

Pressure-leaf filters require much less constant attention than filter presses. For example, two men can operate four or five pressure-leaf machines, each having 1,000 sq. ft. of filter area. A battery of nine or ten such machines will require a foreman and a mechanic in addition to the two operating men, for the most efficient results.

Cloth replacement is a relatively unimportant factor in operation, as compared with filter presses, for two reasons: (1) the filter capacity is usually two or three times greater with pressure-leaf filters than in the press type, and (2) the life of the cloth is increased considerably because of less mechanical wear and tear. As a rule, cotton pressure cloth will last from 6 weeks to 6 months in pressure-leaf filter operation, assuming 10 hr. per day production. The cost of cotton pressure cloth is about 10 cts. per square foot. Other items of maintenance and repair will not exceed 5 per cent per year and may be as low as 3 per cent.

Example of Pressure-leaf Filter Operation.—In this example, calculations are based on the following machine specifications and operating data, and it will be noted that these conditions vary widely from those of the previous example:

1. A battery of nine pressure-leaf filters is to be used, each machine having a net filter area of 1,040 sq. ft.
2. The slurry is a sugar liquor of sp. gr. = 1.27, and kieselguhr is used as a filter aid.
3. Operation is 24 hr. per day, 300 days per year. Production is 500 tons of dry solids per day. The total volume of liquor handled is 167,000 gal. per day, some of which is filtered twice.

Interest.—Referring to Fig. 22, the cost of a pressure-leaf filter with 3-in. spacing and 1,040 sq. ft. area is $7.80 per square foot. The cost of nine such presses will be

$$(7.80)(1{,}040)(9) \qquad = \quad \$73{,}000.$$

The cost of accessory equipment and installation will be 40 per cent of the base machine cost, or

$$(73{,}000)(0.40) \qquad = \qquad \$29{,}200,$$

making the total investment = $102,200.
The daily charge to interest, at 6 per cent per year, will be

$$\frac{(102{,}200)(0.06)}{(300)} \qquad = \qquad \$20.44.$$

Depreciation.—Assuming 10 per cent uniform depreciation per year on the total investment, the daily charge will be

$$\frac{(102{,}200)(0.10)}{(300)} \qquad = \qquad \$34.07.$$

Cost of Power.—Assuming the cost of power to be 1 ct. per horsepower-hour, and the power consumption to be 0.01 hp. per square foot (including pumping and steam for heating liquor) the total power cost for 24 hr. will be

$$(1{,}040)(9)(0.01)(0.01)(24) \qquad = \qquad \$22.50.$$

Cost of Labor.—Two operators are required per 8-hr. shift, at $4. For 24 hr. this is

$$(2)(4.00)(3) \qquad = \qquad \$24.00.$$

Two mechanics are required for one 8-hr. shift, at $5,

$$(2)(5.00) \qquad = \qquad \$10.00.$$

One foreman, per 8-hr. shift, at $5.

$$(1)(5.00)(3) \qquad = \qquad \$15.00,$$

making the total labor per day = $49.00.
Cost of Maintenance and Supplies.—Assuming prepared filter cloth at 11 cts. per square foot, and an expected life of 60 days of 24 hr. each, the daily replacement of cloth will be

$$\frac{(1{,}040)(9)(0.11)}{(60)} \qquad = \qquad \$17.15.$$

Assuming all other maintenance at 3 per cent per year

$$\frac{(102{,}200)(0.03)}{(300)} \qquad = \qquad \$10.22,$$

making the total maintenance and supplies per day = $27.37.

Summary of Costs, Not Including Kieselguhr

		Percentage Analysis
Interest	$ 20.44	13.3
Depreciation	34.07	22.3
Power	22.50	14.7
Labor	49.00	32.0
Maintenance	27.37	17.7
Daily cost	$153.38	100.0

Cost per ton of solids $= \frac{\$153.34}{500} = \$0.31.$

About 3 tons of kieselguhr are used per run of 167,000 gal. liquor. At $50 per ton, this is a daily charge of

$$(3)(50) = \$150.$$

Adding this to the above cost, the total becomes $303.34, or $0.61 per ton of solids.

In contrast with filter-press operation, the foregoing summary shows that labor costs are considerably less with pressure-leaf machines, and that a filter aid, when necessary, is a prominent item of cost.

Vacuum Continuous Filter Operating Costs.—In complete installations of vacuum continuous filters, the auxiliary equipment is from 30 to 50 per cent of the total cost and this is a considerable factor in the determination of an over-all depreciation rate. Conservative practice would indicate a uniform rate of 10 per cent, the same as for other types of filter machines. Under favorable conditions, a lower figure would be allowable.

The power requirements of vacuum continuous machines are relatively high, on account of the load taken by the vacuum pumps. Power will vary enormously with the type of slurry and with the properties of the cake. With mining concentrates, 0.05 hp. per square foot of filter area is a good average figure. Hot solutions having a high vapor pressure should not be run in this type of machine, owing to the limited capacity of the vacuum pumps and excess power necessary for vapor removal.

Of all the types of filters, a vacuum continuous machine will show the greatest labor economy. One attendant is sufficient for every four to six machines, and two operators, together with one mechanic, can operate a battery of 20 vacuum continuous filters. Such low labor costs are due to the absence of cyclic

opening, dumping, and cleaning, and to the fact that the filter medium has a long life.

Maintenance, exclusive of cloth renewals, will average 5 per cent of the total installation cost. On vacuum continuous filters, duck cloth will last from 1 to 2 years in neutral slurries. When the slurry is acidic, woolen cloth is used, and this has a life of from 1 week to 5 months, depending upon the concentration of the acid. Close-woven Monel-metal cloth, as used for filtering caustic-soda slurries, can be depended on for several years of satisfactory service. Monel cloth costs about $2 per square foot, woolen cloth for vacuum filtration costs 20 cts. per square foot, and cotton duck for ordinary work costs 7 to 8 cts. per square foot. On account of the low working pressure, a cheap grade of duck will give good service on vacuum filter machines.

Example of Vacuum Continuous Filter Operation.—In this example, the equipment and operating specifications are as follows:

1. One vacuum continuous filter is used having a net area of 600 sq. ft.

2. The slurry is calcium carbonate in caustic liquor, a fairly free-filtering material the rate of which is about 700 lb. dry solids per square foot of filter area per day.

3. Operation is 24 hr. per day, 300 days a year. Production is 200 tons of solids per day.

Interest.—Reference to Fig. 23 will show that a vacuum continuous filter, without accessories, costs $11.21 per square foot, assuming 600 sq. ft. capacity. The machine cost will be

$$(11.21)(600) \qquad = \qquad \$6{,}725.$$

Assuming the cost of accessory equipment as 40 per cent of the base cost, this will add

$$(6{,}725)(0.40) \qquad = \qquad \$2{,}690.$$

The installation cost will be about 25 per cent of the filter cost

$$(6{,}725)(0.25) \qquad = \qquad \$1{,}681.$$

making the total investment = $11,096.

The daily interest charge, at 6 per cent per year, will be

$$\frac{(11{,}096)(0.06)}{(300)} \qquad = \qquad \$2.22.$$

Depreciation.—Assuming 10 per cent uniform depreciation per year on the total investment, the daily charge will be

$$\frac{(11{,}096)(0.10)}{(300)} = \$3.70.$$

Cost of Power.—Assuming the cost of power to be 1 ct. per horsepower-hour and the power consumption 0.05 hp. per square foot filter area, the total power consumption for 24 hr. will be

$$(600)(0.05)(0.01)(24) = \$7.20.$$

Cost of Labor.—In a small installation, such as this, assume the half time of one man on each 8-hr. shift. At \$4 per day, this will be

$$\frac{(4.00)(3)}{(2)} = \$6.00.$$

Cost of Maintenance and Supplies.—Assuming the use of Monel-metal cloth at \$2 per square foot and having a life of 2 years, cloth replacement per day will be

$$\frac{(600)(2.00)}{(2)(300)} = \$2.00.$$

Assuming all other maintenance and repairs to be 5 per cent on the total investment, this will be

$$\frac{(11{,}096)(0.05)}{(300)} = \$1.85,$$

making the total maintenance and supplies per day = \$3.85.

Summary of Costs

		Percentage Analysis
Interest	\$ 2.22	9.7
Depreciation	3.70	16.1
Power	7.20	31.3
Labor	6.00	26.1
Maintenance	3.85	16.8
Daily cost	\$22.97	100.0

$$\text{Cost per ton of solids} = \frac{\$22.97}{200} = \$0.11.$$

From the foregoing summary, it will be seen that power and fixed charges are relatively important items in vacuum continu-

ous filter operation and that such a filter is, therefore, best adapted to 24-hr. a day operation.

EVAPORATOR COSTS

In the following section, evaporators are classified into five groups, and equipment costs for each group are shown in terms of dollars per square foot of heating surface. Various factors in operating cost are illustrated, including economic balance in multiple-effect equipment.

Classification of Evaporator Bodies.—Although a number of distinct evaporator types are possible, depending upon the method of removing the evolved vapor and of supplying the heat of vaporization, only that type in which the vapor is removed in undiluted form, and in which the heat of vaporization is supplied by condensing steam will be considered.

Different means of supplying the heat of vaporization and of removing the evolved vapor have caused a wide variation in the design of evaporator bodies. Thus, the tubular heating surface may be horizontal, vertical, or inclined; the steam may be either inside or outside the tubes; and the liquor may either submerge the heating surface or simply film it. Five distinct evaporator types are important commercially, the following being a brief description of them:

1. *Tubes Horizontal, Liquor Outside, Heating Surface Submerged.*—This is probably the most common type of evaporator, and it possesses the desirable features of simplicity and strength. A good example of this type is the Swenson.

2. *Tubes Horizontal, Liquor Outside in Film Form.*—Because of positive liquor circulation and the relatively short time of contact between the liquor and the heating surface, this type of evaporator is well suited to liquors of high concentration. The Lillie belongs to this type.

3. *Tubes Horizontal, Liquor Inside, Heating Surface Submerged.*—This rapid-circulation type has the added advantage of positive liquor contact with the heating surface and is adapted especially to liquors sensitive to heat. The Yaryan is an example of this type.

4. *Tubes Vertical, Liquor Inside, Heating Surface Submerged.*—In this evaporator, good natural convection is obtained by means of a large central downtake. The ease with which incrustations

can be removed from the tube surfaces also is a feature. This is known as the standard vertical type.

5. *Tubes Vertical, Liquor Inside in Rapid Circulation.*—The liquor velocity attained in the heating tubes makes possible a high over-all coefficient of heat transfer. This type is suited to an extremely wide range of materials and is illustrated by the Buflovak rapid-circulation evaporator.

Evaporator Auxiliaries.—Every evaporator body must be equipped with auxiliary equipment for removing condensed water and noncondensable gases, evolved vapor, and liquor. In salting-out evaporators, special means must be provided for separating crystallized solids; and with liquors that foam excessively, provision should be made for separating vapor from the boiling liquor. A wet-vacuum pump can be employed to remove the condensed water from the heating element, and a condenser of either the jet or the surface type, in series with a vacuum pump, is necessary for removing the evolved vapor.

The type of evaporator depends upon the work being done. Many liquors, however, can be concentrated satisfactorily in practically every type of evaporator, and for these Kerr[1] gives the relative evaporative capacity as follows:

1. Horizontal, submerged-tube type, 100.
2. Vertical, submerged-tube type, 100.
3. Rapid-circulation type, horizontal or inclined tubes, 130.
4. Rapid-circulation type, vertical tubes, 150.

A factor of even more importance than machine type is scale formation. McCabe and Robinson[2] have studied the effect of scale upon the over-all coefficient of heat transfer in evaporator heating surfaces. From the results of work by three independent investigators, it was found that the coefficient H varied with time and with the solution, in accordance with the equation,

$$\frac{1}{H^2} \quad c\theta + \text{constant},$$

when H = the over-all coefficient of heat transfer.
θ = time.
c = a proportionality constant.

Starting with clean tubes, and evaporating concentrated inor-

[1] *Trans. A.S.M.E.*, **38**, 67 (1916).
[2] "Evaporator Scale Formation," *Ind. Eng. Chem.*, **16**, 478 (1924).

ganic salt solutions, it was found that the scale formed in from 2 to 5 hr. was sufficient to reduce the initial value of H by 50 per cent. The economy of maintaining clean tubes is obvious. For a more extended survey of evaporator equipment and operation, reference should be made to the excellent treatise by Badger.[1]

Cost of Evaporator Equipment.—The cost of evaporators cannot be expressed satisfactorily in terms of any simple capac-

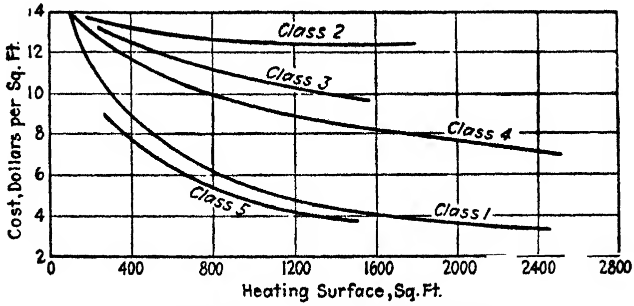

FIG. 25.—Cost of evaporator bodies.

Cost is expressed in dollars per square foot of heating surface for one effect without condenser and pumps.

Class 1—Tubes horizontal, liquor outside, tubes submerged.
Class 2—Tubes horizontal, liquor outside, in film form.
Class 3—Tubes horizontal, liquor inside, rapid circulation.
Class 4—Tubes vertical, liquor inside, submerged type.
Class 5—Tubes vertical, liquor inside, rapid circulation.

ity function, because of the many variables. Design varies greatly with different types. The terminal conditions of operation, that is, temperature and pressure and the kind of liquor, furthermore, are controlling factors in evaporative capacity. It is possible, however, to express costs in terms of heating surface for a single-effect unit, exclusive of such auxiliary equipment as pumps and condensers. Knowing the type of evaporator best adapted to a liquor and the evaporative capacity to be expected, both equipment and operating costs can be predicted with reasonable accuracy.

Figure 25 shows the cost of single-effect evaporators, exclusive of auxiliary equipment. The classification is the same as was used in the description of equipment in the foregoing section.

[1] "Heat Transfer and Evaporation," Reinhold Publishing Corporation, New York (1926).

Calculation of the required initial investment presupposes a knowledge of the following engineering data:

1. The types of evaporator that are suitable, and the proper materials of construction.
2. The probable evaporation per square foot of heating surface, under the specified operating conditions.
3. The number of effects in the system. This is determined by an economic balance between the fixed charges on the investment and the operating costs.

Once the necessary heating surface has been determined, the cost of the evaporator effects alone is obtained by reference to the cost curves in Fig. 25. For example, suppose that 2,000 sq. ft. of total heating surface is required in a triple-effect horizontal tube evaporator of the submerged type having the liquor outside the tubes. Each effect will have approximately 700 sq. ft. of heating surface costing \$6.50 per square foot, and the cost for three effects will be

$$(3)(700)(6.50) = \$13,650,$$

when iron tubes and cast-iron bodies are specified. The necessary auxiliary equipment, including condenser, vacuum pumps, and liquor pumps, will add about 30 per cent to the above base cost, and the cost of installation and piping will amount to 25 per cent of the over-all equipment cost, making the total initial investment

$$(13,650)(1.30)(1.25) = \$22,200.$$

The cost of auxiliary equipment varies considerably and is substantially a function of the amount of vapor and liquor. Condensers average from 8 to 10 per cent of the base cost, being as low as 5 per cent in large multiple-effect installations, and as high as 20 per cent for small evaporators.

Vacuum pumps average 16 to 20 per cent of the base cost, and again, the variation may be from 10 to 40 per cent of the base cost, the smaller percentage being applicable to large installations. Salt catches, when needed, add about 10 per cent to the base cost. Liquor pumps and minor accessories add another 5 per cent.

Installation cost depends considerably upon local prices of material and labor. When the cost of piping and of heat insula-

tion is charged to installation, 15 per cent of the cost of evaporator plus auxiliaries is probably a minimum figure, and 25 to 30 per cent is a fair upper limit.

In multiple-effect systems, condenser costs are lowered nearly in proportion to the number of effects. The same rule applies in theory to the vacuum pumps, although due to the high ratio of noncondensable gas to steam, not much reduction is obtained in actual practice. Liquor pumps and other accessories are required proportional to the number of effects. The net result is that the over-all charge for auxiliaries increases nearly in proportion to the number of effects, independent of the type or capacity of the evaporator.

Another variable in equipment costs arises from the materials of construction. The substitution of copper tubes for iron tubes increases the base cost for each effect about 5 to 10 per cent, according to the price of copper and the type of evaporator. Steel body construction and tubes cost about 20 per cent less than does the usual iron construction. Rapid-circulation evaporators, constructed entirely of copper, cost from 100 to 120 per cent more than do evaporators with cast-iron bodies and copper tubes.

The ordinary vertical type of evaporator, when equipped with submerged lead tubes and lead-lined body, costs 150 per cent more than the regular iron construction. The cost of other special types of construction is difficult to express on any definite basis and does not depend to any extent upon competitive factors.

Evaporator Operating Costs.—Operating costs in evaporation can be classified as follows:

1. Interest on investment.
2. Depreciation.
3. Taxes and insurance.
4. Steam for evaporation and for power.
5. Cooling water.
6. Direct labor.
7. Maintenance and supplies.

Fixed charges in evaporator practice are much easier to determine than are the items due strictly to operation, such as steam, cooling water, labor, and maintenance. Interest on the investment is 6 per cent. Depreciation depends upon the work being done. Although many installations have been in service for

30 years, others have to be scrapped within 10 years, or even less. It is safe, however, to call the average useful life of an evaporator 20 years, charging a uniform 5 per cent per year depreciation. Taxes and insurance rarely exceed 3 per cent of the initial investment.

Methods of costing steam vary widely, as the exhaust from noncondensing engines can be used for evaporation, and it is clear that, when this is done, the cost of steam is not chargeable entirely either to the power plant or to the evaporator house.

For present purposes, steam for evaporation will be charged at an arbitrary figure of 40 cts. per 1,000 lb. In the calculation of steam consumption for evaporation, it is safe to assume from 0.80 to $0.90N$ lb. of water evaporated per pound of steam, when $N =$ the number of effects. The approximate steam consumption for auxiliary equipment will be between 8 and 15 per cent of that needed for evaporation, in a triple-effect installation. Pump efficiency, capacity, and the number of effects constitute the major variables. An approximation of power requirements can be obtained also by assuming the steam consumption of dry-vacuum pumps to be 50 lb. per horsepower-hour, and for wet-vacuum and liquor pumps 100 lb. per horsepower-hour. Some allowance should be made for the fact that about 85 per cent of the steam used by the auxiliaries can be exhausted to the evaporators.

Cooling water requirements are proportional to the amount of steam used for evaporation, the temperature of injection, and the vacuum maintained in the last evaporator effect. The type of condenser will cause some variation in the amount of cooling water. A safe allowance is 30 lb. of cooling water per pound of steam, assuming an entrance temperature of 70°F. and a vacuum of 26 in. in the last effect. Although municipal water rates vary from 50 cts. to $1.00 per 1,000 cu. ft., water can be pumped from near-by sources at a cost of about 15 cts. per 1,000 cu. ft.

Labor requirements vary from one man, who can operate any small machine up to an ordinary triple-effect having about 700 sq. ft. heating surface, to four men necessary for the operation of the largest size quadruple-effect salting evaporator. As a rule, one man can operate any single-effect or multiple-effect evaporator, working on easy-boiling material, such as glucose, and have other responsibilities as well. The extra men required

for complicated stations usually are classed as helpers and receive less wages than do the operators.

Maintenance and repairs should be about 6 per cent of the total investment annually. Tube replacements and cleaning constitute the greatest source of expense. The magnitude of these items varies greatly, according to the liquor evaporated, and is difficult to generalize with any degree of accuracy.

Example of Evaporator Operation.—Black liquor from the soda digestion of wood in a pulp mill is to be evaporated from 7°Bé. (sp. gr. = 1.05) to 36°Bé. (sp. gr. = 1.33) in a quadruple-effect horizontal submerged-tube evaporator. Exhaust steam from 5 to 10 lb. gage is available for evaporation, and a 26-in. to 27-in. vacuum is maintained in the last effect. A total of 70,000 gal. of liquor is to be concentrated daily, giving 10,800 gal. of product, and evaporating 490,000 lb. of water. The total daily steam consumption is 148,000 lb., of which 145,000 lb. is condensed in the evaporator. Each effect has 1,800 sq. ft. of heating surface, consisting of charcoal-iron tubes. Tests show that 3.40 lb. of water can be evaporated per pound of steam. Under present conditions of operation, the capacity of the evaporator is limited by foaming. What is the cost of evaporation?

Solution.—From Fig. 25 it will be seen that a horizontal submerged-tube evaporator of Class 1 having 1,800 sq. ft. of heating surface costs

$$(1,800)(3.80) = \$6,840 \text{ per effect.}$$

As there are four effects, the base cost will be (4)(6,840) = \$27,360. This being a large installation, an allowance of 8 per cent for a condenser, 16 per cent for vacuum pumps and 5 per cent for liquor pumps and minor accessories is conservative. An additional 6 per cent should be included to provide for special separator construction, which is practically essential in the evaporation of a foaming material such as black liquor. The cost of evaporator, complete with accessories, will then be

$$(27,360)(1.35) = \$36,936.$$

The cost of installation, including all pipe connections, foundations, and lagging, will not exceed 25 per cent of the over-all equipment cost, making the total investment (36,936)(1.25) = \$46,170, upon which the daily interest charges are

$$\frac{(46{,}170)(0.06)}{(300)} = \$9.23.$$

Depreciation at 5 per cent will be

$$\frac{(46{,}170)(0.05)}{(300)} = \$7.68.$$

Taxes and insurance at 3 per cent are

$$\frac{(46{,}170)(0.03)}{(300)} = \$4.62.$$

Steam costs, charging 40 cts. per 1,000 lb., will be

$$\frac{(148{,}000)(0.40)}{(1{,}000)} = \$59.20.$$

Cooling water is pumped from a near-by river at a cost of 15 cts. per 1,000 cu. ft. Allowing 30 lb. of water per pound of steam condensed, this will be

$$\frac{(148{,}000)(30)(0.15)}{(1{,}000)(62.5)} = \$10.65.$$

One operator at $5 will be needed for each of three 8-hr. shifts, making the labor charge

$$(5.00)(3) = \$15.$$

Maintenance of equipment and repairs at 6 per cent on the initial investment will be

$$\frac{(46{,}170)(0.06)}{(300)} = \$9.23.$$

Summary of Costs

		Percentage Analysis
Interest on investment	$ 9.23	8.0
Depreciation	7.68	6.6
Taxes and insurance	4.62	4.0
Steam	59.20	51.2
Cooling water	10.65	9.2
Labor	15.00	13.0
Maintenance	9.23	8.0
Total daily cost	$115.61	100.0

As 490,000 lb. of water is evaporated daily, the unit cost of evaporation is

$$\frac{(115.61)(1{,}000)}{(490{,}000)} = \$0.24 \text{ per 1,000 lb. water evaporated.}$$

Economic Balance in Evaporator Operation.—In any large-scale process, multiple-effect evaporation generally is indicated, unless fuel costs are extremely low, or unless a very corrosive liquor is being handled. In theory, 1 lb. of steam will evaporate N lb. of water, when N = the number of effects; but the actual results attained in practice vary widely. Furthermore, an increase in the number of effects causes a nearly proportionate increase in the initial investment.

From the foregoing it will be seen that the determination of the number of effects N in a multiple-effect system resolves into a problem of economic balance between the fixed charges on the investment and the cost of steam and cooling water. The optimum number of effects will vary with the cost of fuel and equipment, and as a rule, more than five effects are seldom justified, except in the large-scale evaporation of extremely dilute solutions. The following example will serve to illustrate the principle of economic balance in operation:

It is desired to evaporate 150,000 lb. of water per day from a saturated salt liquor, using a vertical submerged-tube evaporator equipped with salt catches. Assume the following conditions:

1. Operation is 24 hr. per day, 300 days per year.
2. Labor is the same for any number of effects.
3. Steam at 40 cts. per 1,000 lb. is available. The cost of cooling water can be neglected.
4. Evaporation in a single effect is at the rate of 10 lb. per square foot per hour and 0.80 lb. of water can be evaporated per pound of steam, as shown by test.
5. The total annual fixed charges, including depreciation, repairs, taxes, insurance, interest, and 20 per cent return on the investment above interest are 40 per cent of the investment.

In calculating the optimum number of effects, the expected rate of return on the investment is included in the fixed charges. This return is assumed to be 20 per cent, although the nominal rate of interest alone is 6 per cent.

A single-effect evaporator of sufficient capacity, together with all accessories, and installed ready for operation, will cost \$11,000. Assuming N effects, the fixed charges per day will be

$$\frac{(11{,}000)(0.40)(N)}{(300)} = \$14.67N.$$

The steam cost will be

$$\frac{(150{,}000)(1)(0.40)}{(0.80)(N)(1{,}000)} = \frac{\$75}{N}.$$

The resulting summation of fixed charges and steam cost for a varying number of effects is shown in Table VI.

TABLE VI.—OPTIMUM NUMBER OF EFFECTS FOR EVAPORATOR

	One effect	Two effects	Three effects	Four effects	Five effects
Fixed charges	$14.67	$29.33	$44.01	$58.67	$73.35
Steam	75.00	37.50	25.00	18.75	15.00
Total	$89.67	$66.83	$69.01	$77.42	$88.35

The optimum number of effects can be calculated from the equation

$$\text{Total daily cost} = 14.67N + \frac{75.00}{N}$$

which, differentiated with respect to the number of effects and equated to zero, is

$$N = \sqrt{\frac{\text{Cost steam}}{\text{Fixed charges}}} = \sqrt{\frac{75.00}{14.67}} = 2.27.$$

This equation is also represented graphically by Fig. 26.

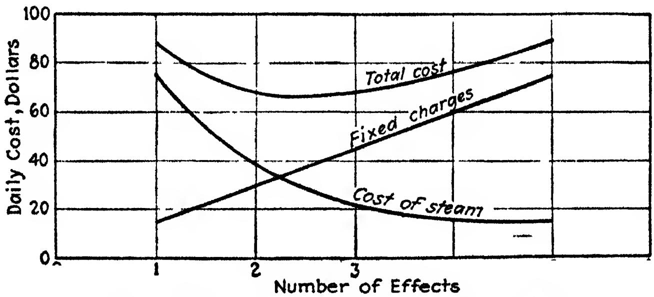

FIG. 26.—Economic balance in evaporator operation. Showing the optimum number of effects for multiple-effect operation.

Another desirable feature of multiple-effect systems is flexibility. At times of considerable overload, the effects can be operated singly; that is, in parallel, thus securing high capacity,

and at ordinary loads the economy of series-multiple operation can be realized. Should such peak-load operation be expected, it will be necessary to provide sufficient condenser and pump capacity in the original installation. For a more detailed discussion of economic balance in evaporator operation, reference should be made to Walker, Lewis and McAdams.[1]

CRUSHING AND GRINDING COSTS

In this section, the equipment costs and operating costs of modern grinding equipment are considered. Technical aspects of crushing and grinding are discussed only in relation to choice of equipment and operation for minimum cost.

Classification of Crushing and Grinding Equipment.—Crushing and grinding machines can be classified into three major groups, as follows:

1. Preliminary, or coarse crushers, which are designed to take a feed as large as 60 in., giving a product of 1½ in. or finer.
2. Fine crushers, which take a feed of about 1½ in. and give a product of ¼ to ⅛ in.
3. Fine pulverizers, which take a feed as large as 1 in., but usually ½ in. or less, the product being 100-mesh or about 90 per cent through 200-mesh. Some engineers introduce a fourth class, termed intermediate crushers, the function of which is to reduce feeds of from 6 to 1½ in. to about ¼ in.

Another system of classification is possible, based on the mechanism of rock subdivision. For example, there are machines that crush by pressure, such as the jaw crushers; others that crush mainly by impact, and still another class in which the material is sheared, or torn apart.

Selection of crushing machinery, therefore, depends largely upon two factors: (1) the range of reduction in size, and (2) the physical properties of the material to be reduced. The more important physical properties to be considered are hardness, mechanical structure, and moisture content.

Preliminary Crushers.—The jaw crusher is perhaps the best-known machine of the primary type. Crushing action is obtained by reciprocating a pivoted jaw against a fixed jaw. These

[1] "Principles of Chemical Engineering," McGraw-Hill Book Company, Inc., New York (1937).

machines are characterized by mechanical simplicity and ruggedness.

For large capacities, however, the gyratory crusher is preferable, as it consumes less power. In this type of crusher, the rock is broken by a conical member rotating eccentrically against a fixed external funnel-shaped member. The product of the gyratory crusher is uniform, as compared with that of the jaw crusher. Both machines take feeds as large as 60 in., and deliver a product of 1½ in., or finer.

Fine Crushers.—Fine crushers include crushing rolls, rotary crushers, and gravity stamps. Of these machines, crushing rolls are the most important, and these are adapted especially to brittle material that is to be reduced to ⅛ in. or so. Beyond this point, the fines tend to choke the rolls, causing excessive power consumption. Crushing rolls are mounted in pairs, crushing action being obtained by the convergent travel of the roll faces, the material first being "nipped" and then crushed by pressure. The diameter of the rolls determines, to a large degree, the maximum allowable size of feed, and the space between them regulates the maximum size of product.

Rotary crushers are designed for reducing brittle material of medium hardness, such as coal. In this mill, a fluted conical member rotates within a grooved and fixed grinding ring, the size of product being regulated by the clearance between the grinding elements.

Gravity stamps are a special type of impact crusher used almost exclusively in the mining industry for reducing gold-bearing quartz. Stamps are wasteful of power, and the product from them is not at all uniform. Crushing is effected by the impact of falling hammers, water being used to sluice out the product.

Fine Pulverizers.—The important machines in this class are ball mills, tube mills, rod mills, centrifugal-roll mills, and impact or swing-hammer pulverizers. Other more specialized types include buhrstone mills and edge runners.

Ball mills, because of their simplicity of construction and comparatively low maintenance cost, are used in many divergent industries with marked success. Reduction is accomplished by the impact and shear caused by the contact of steel balls or flint pebbles upon each other. A ball mill consists of a closed cylindrical shell, suitably lined and containing the charge of balls.

The slow rotation of the cylinder upon its axis produces the required tumbling action.

In principle, tube mills are simply elongated ball mills. This design makes possible a product of extreme fineness. In general, ball mills are used for relatively coarse grinding, and tube mills for the finer work up to 200-mesh or so.

Another important modification of the ball mill is the rod mill, in which a charge of rods the length of the mill constitutes the

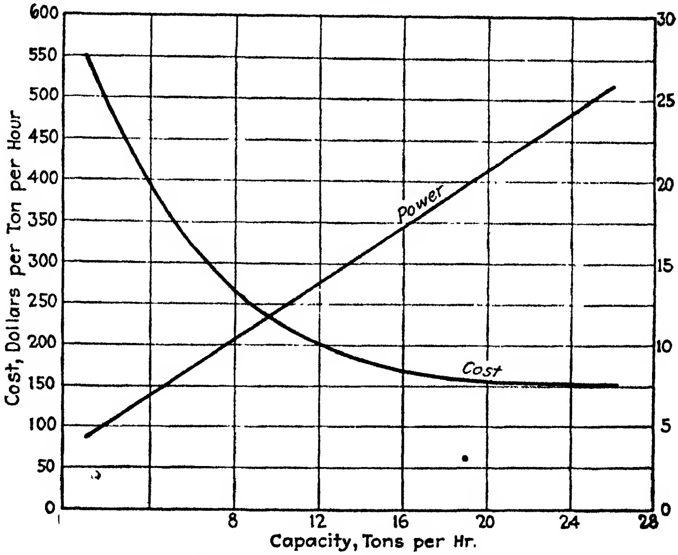

FIG. 27.—Cost of jaw crushers.

Cost is expressed in dollars per ton-hour output, based on approximate capacity on hard limestone with feed of 6 to 14 in. and product of $1\frac{1}{2}$ to $3\frac{1}{2}$ in.

grinding element. This mill, as well as ball and tube mills, operates best either on a very dry feed, or on one that is pulpy and contains a large proportion of water.

The fine grinding of soft and moderately hard friable materials is accomplished efficiently by centrifugal-roll or ring-roll mills. In this general type of mill, one member, consisting of one or more rolls attached to hinged spider arms, rotates over the inside surface of a grinding ring, reduction being accomplished by a combination of pressure and shear. There are at least six mills operating on the ring-roll or ring-and-ball principle, the distinguishing features being the method of feeding and of separating the product.

Impact or swing-hammer pulverizers consist of a series of rotating hammers or bars swinging within a housing, the bottom part of which is a discharge grating or "grizzly," set to the desired fineness of product. With these machines it is possible to grind a wide range of materials, varying in hardness and mechanical structure from limestone to wood chips.

Cost of Crushing and Grinding Equipment.—It is difficult to express the cost of crushing and grinding equipment as a function of any dimensional factor. There are, however, a number common materials such as limestone, phosphate rock, and coal

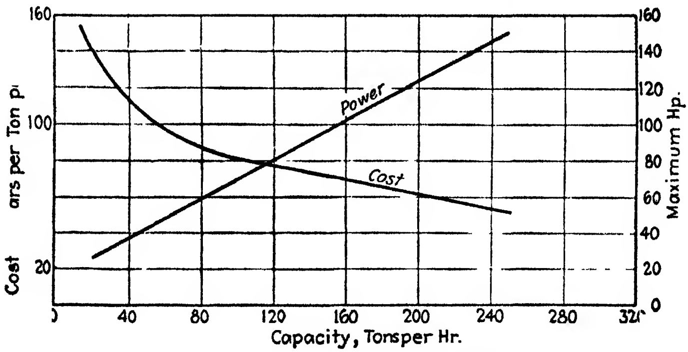

Fig. 28.—Cost of gyratory breakers.
Cost is expressed in dollars per ton-hour output, based on approximate capacity on hard limestone with feed of 6 to 14 in. and product of 1½ to 3½ in.

which can be used as a basis of capacity and therefore of cost, when expressed as dollars per ton capacity per hour.

The cost of various types of machines can be expressed graphically. Figures 27 and 28 show the cost of preliminary crushers of both the jaw and gyratory types, the basis of capacity being hard limestone crushed between definite limits. At the outset it is realized that certain important factors affecting capacity, such as moisture content, hardness, and mechanical structure, must be considered in every estimate of performance. For this reason, only common materials have been chosen as standards, and in every example, the capacity expressed is the conservative estimate of equipment manufacturers.

Costs for jaw and gyratory crushers are not exactly comparable, as the range of capacity differs. Machines of the gyratory type operate to best advantage on large tonnages and in a continuous process. On the other hand, jaw crushers are

indicated when operation is intermittent and on a smaller scale. For capacities of less than 10 tons per hour, the jaw crusher usually is preferred, as a smaller initial investment is required.

For intermediate and fine crushing, single and multiple rolls, rotary fine crushers and swing-hammer mills are used commonly. The cost of these machines is shown in Figs. 29 and 30. Here,

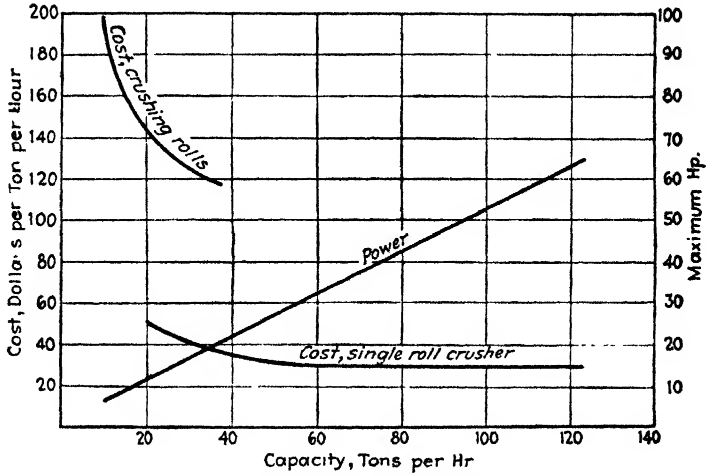

FIG. 29.—Cost of crushing rolls.
Cost is expressed in dollars per ton-hour output, based on approximate capacity on medium bituminous coal with feed of 6 in. or less and product of 1 in. or less.

again, costs are expressed on the basis of capacity when crushing such materials as bituminous coal and limestone.

The cost of two distinct types of fine pulverizing machines is shown in Figs. 31 and 32. Figure 31 shows the cost of ball mills plotted as a function of grinding capacity. Tube mills will cost about the same, as they are merely elongated ball mills. Special rod mills of heavy construction, for grinding hard material, cost twice as much as does the usual type of ball mill. Linings made of special hardened steels cost from 15 to 20 per cent of the cost of the mill.

Another markedly successful type of fine pulverizing machine is the ring-roll mill in its various modifications. Ring-roll mills, as will be seen from Fig. 32, are the most expensive type of grinding machine in common use. The cost, however, as expressed in the curve, includes a separating device and a feed mechanism. Owing to the high grinding efficiency of these mills,

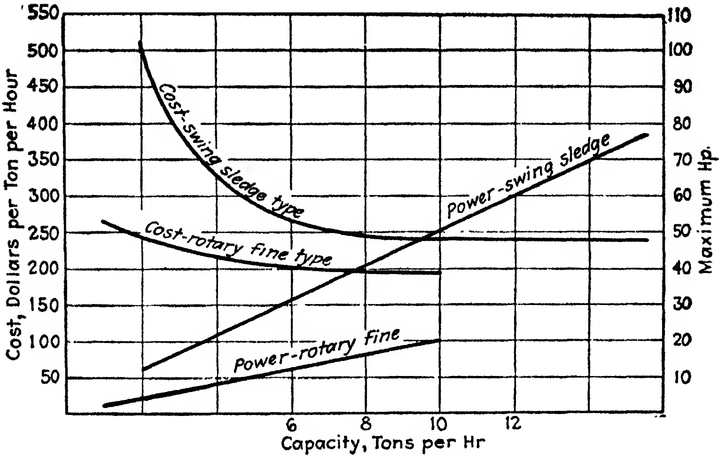

FIG. 30.—Cost of fine crushers.

Cost is expressed in dollars per ton-hour output, based on (1) medium limestone with feed of 3 in. and product of ⅛ in. or less for swing-sledge type and (2) medium limestone with feed of 3 to 8 in. and product of ¼ in. or less for rotary fine type.

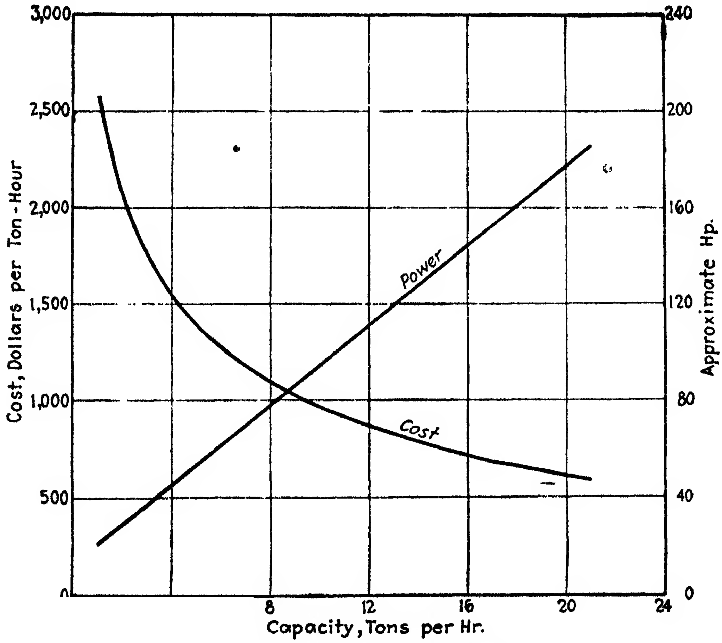

FIG. 31.—Cost of ball mills.

Cost is expressed in dollars per ton-hour output, based on 5-in., 4-in. and 3-in. balls grinding limestone from 1½ in. to 48-mesh.

the over-all operating cost per ton may be very low, thus amply justifying the investment.

Auxiliary Equipment and Installation Costs.—Every crushing mill requires considerable auxiliary machinery for handling materials and for screening. These include elevators, feeding devices, conveyor belts, screens, and magnetic separators, which in total may represent an investment greater than that in the mill itself. Requirements with respect to auxiliaries vary to

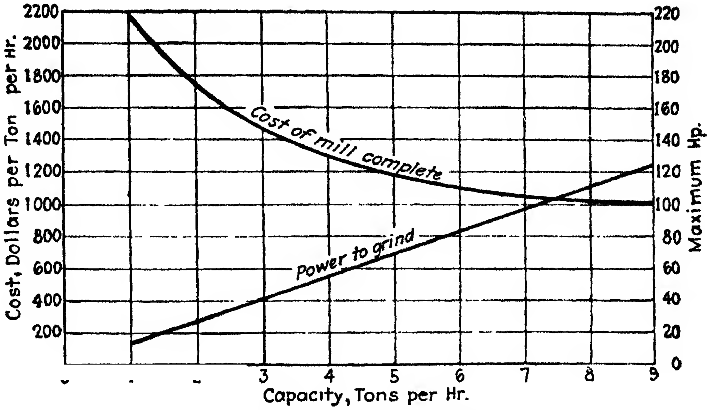

FIG. 32.—Cost of ring-roll pulverizers.

Cost is expressed in dollars per ton-hour output, complete with air separator, feeding equipment, and belt drive. Basis of performance is bituminous coal with feed of 1 in. or less and product of 95 per cent through 100-mesh.

such an extent that no attempt will be made to standardize these costs.

An element of great importance in the initial outlay for crushing equipment is installation. With heavy tube mills requiring massive foundation blocks, freight plus installation may be as great as the factory price. This is much above the average installation cost, but it serves to indicate the possible magnitude of such costs. A point worth noting is that the initial investment represented by installation cost has no salvage value.

Operating Costs.—Depreciation constitutes the largest single fixed charge, and on most grinding machines this is about 10 per cent annually. Interest is 6 per cent. Taxes and insurance will fall within 3 per cent.

The outstanding item in operating cost is power, which can be predicted with reasonable certainty for common materials.

As a rule, at least 50 per cent overload power is required to start a mill, and heavily loaded ball or tube mills need from two to five times the normal operating power for starting. The average power requirements of various types of mills are plotted as a function of capacity in Figs. 27 to 32.

Maintenance includes the replacement of the grinding elements and bearings, which in any well-designed mill are easily removable. Maintenance from ordinary wear and tear is directly proportional to the tonnage ground.

The expense of new grinding elements, the accessibility of moving parts and time lost during the repair period all are factors in the selection of equipment. Although the actual cost of maintenance is best calculated from records of performance, high-speed machines unquestionably are the most expensive to keep in good running order.

Labor charges, although an important item in small installations, are not controlling in the operating costs of large installations. For example, two men can operate a 400-ton grinding plant about as easily as a 100-ton plant. Power and maintenance increase nearly in direct proportion to the output.

Examples of Grinding Cost.—I. Tennessee phosphate rock is to be ground to 95 per cent through 100-mesh in a battery of two ring-roll mills. Operating tests show that the capacity of each mill is 5.0 tons of rock per hour, the power consumption being 17.8 hp.-hr. per ton of material ground. Operation is 23 hr. per day, 300 days per year. One man is required for attendance on each of the two shifts. What is the cost per ton of material ground?

Solution.—The cost of ring-roll mills is shown in Fig. 32. As the capacity of these mills on phosphate rock and bituminous coal does not vary more than 10 per cent, the cost curve may be used without correction. The mill cost will be

$$(2)(5)(1,200) = \$12,000.$$

Assuming freight charges and installation costs to be 40 per cent of the base factory cost, the total investment exclusive of material-handling equipment will be

$$(1.40)(12,000) = \$16,800.$$

Interest at 6 per cent will be

$$\frac{(16{,}800)(0.06)}{(300)} = \$3.36 \text{ per day.}$$

Depreciation at an average of 10 per cent will be

$$\frac{(16{,}800)(0.10)}{(300)} = \$5.60 \text{ per day.}$$

Taxes and insurance add another 3 per cent

$$\frac{(16{,}800)(0.03)}{(300)} = \$1.68 \text{ per day.}$$

Power at 2 cts. per kilowatt-hour will be

$$(0.02)(0.746)(17.8)(2)(5)(23) = \$61.20 \text{ per day.}$$

Labor at 50 cts. per man-hour will be

$$(0.50)(24) = \$12 \text{ per day.}$$

Total maintenance, including repairs, will not exceed 20 per cent of the initial investment, or

$$\frac{(16{,}800)(0.20)}{(300)} = \$11.20 \text{ per day.}$$

Summary of Costs*

		Percentage Analysis
Interest on investment	$ 3.36	3.5
Depreciation	5.60	5.9
Taxes and insurance	1.68	1.8
Power	61.20	64.4
Labor	12.00	12.6
Maintenance and repairs	11.20	11.8
Total daily cost	$95.04	100.0

The cost per ton of material ground is therefore:

$$\frac{(95.04)(100)}{(2)(5)(23)} = 41.3 \text{ cts. per ton.}$$

II. Medium-hard limestone is to be reduced from ¼ in. to 95 per cent through 40-mesh in a 4 × 8-ft. rod mill that has a charge of 6 tons of rods and is equipped with chilled-iron liners. The output under these conditions is 6.2 tons per hour, and the power consumption averages 46 hp. Operation is 23 hr. per day, 300

days per year and 6 man-hr. of labor is chargeable to operation per day. What is the unit cost of reduction?

Solution.—The factory cost of a mill of this type, complete with liners and a charge of rods, is \$5,400. Assuming freight and installation to be 60 per cent of the factory cost, the total initial investment will be

$$(1.60)(5{,}400) = \$8{,}640.$$

The total fixed charges, including interest at 6 per cent, depreciation at 10 per cent, and taxes and insurance at 3 per cent, will be

$$\frac{(8{,}640)(0.19)}{(300)} = \$5.47 \text{ per day.}$$

Power at 2 cts. per kilowatt-hour will be

$$(0.02)(0.746)(46)(23) = \$15.80 \text{ per day.}$$

Labor at 50 cts. per man-hour will be

$$(0.50)(6) = \$3 \text{ per day.}$$

Maintenance and repairs, consisting largely of relining expense, replacement of rods and cost of lubrication, will be about 15 per cent of the initial investment, or

$$\frac{(8{,}640)(0.15)}{(300)} = \$4.32 \text{ per day.}$$

Summary of Costs

		Percentage Analysis
Interest on investment	\$ 1.72	6.0
Depreciation	2.88	10.1
Taxes and insurance	0.86	3.0
Power	15.80	55.3
Labor	3.00	10.5
Maintenance and repairs	4.32	15.1
Total daily cost	\$28.58	100.0

The unit cost of reduction is therefore:

$$\frac{(28.58)(100)}{(6.2)(23)} = 20.1 \text{ cts. per ton.}$$

The foregoing illustrations indicate the relation of the various fixed and operating costs. In general, power is the largest

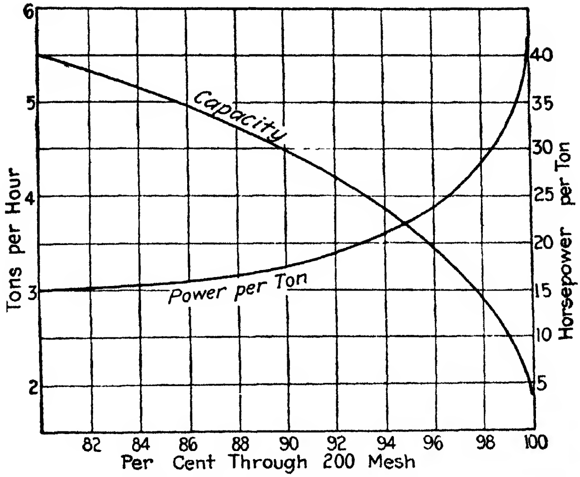

FIG. 33.—Relation of fineness and capacity to power consumption.

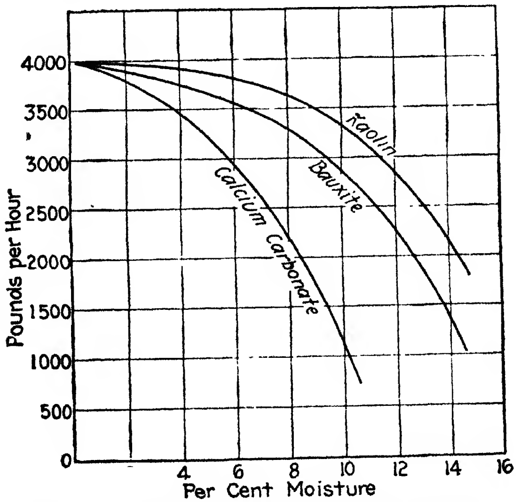

FIG. 34.—Relation of moisture content to capacity.

single item, and opportunities to reduce power consumption by regulating the moisture content of the feed, the fineness of the product, and by selecting the right equipment should be investigated for each set of conditions.

The importance of specifying a product of definite fineness is shown by Fig. 33, the data of which represent operation with air separation, and grinding a material similar to barytes. In this example, Kanowitz[1] points out that when grinding to a fineness of 80 per cent through 200-mesh, the capacity is nearly four times

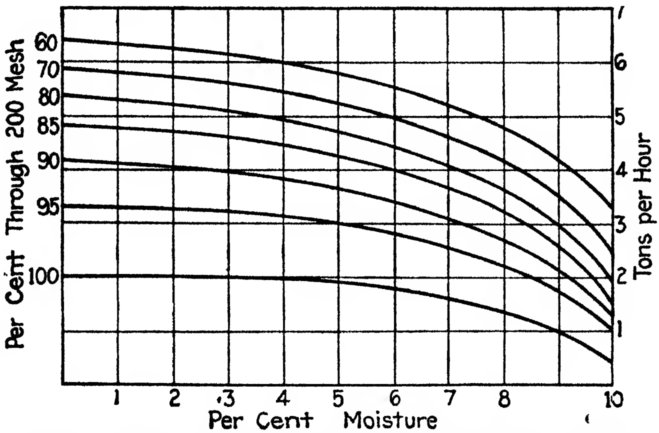

FIG. 35.—Relation of moisture content and fineness to capacity.

as great as when grinding to 100 per cent through 200-mesh. The power consumption, furthermore, increases from 15 to about 45 hp., then operating on the same material. As power is the largest item of cost, the significance of fineness of product is apparent, and too much emphasis cannot be put on specifications of screen analyses.

Moisture content of the feed is another property that has an important effect on capacity. Kanowitz has shown that with increasing moisture, assuming the fineness of the product to be constant, the capacity falls off in accordance with the curves in Fig. 34. It will be noted that the rate of decrease is not the same for all materials. For example, at 10 per cent moisture, the capacity with kaolin is about three times that with calcium

[1] "Modern Pulverizing Methods," *Chem. Met. Eng.*, 32, 199 (1925).

carbonate. When the approximate moisture of the feed is known, an intelligent choice of equipment can be made.

Figure 35 shows the variation in capacity with variable moisture content, and these curves indicate clearly the economic limits of drying the feed.

MISCELLANEOUS COSTS

The following miscellaneous cost data are intended for use in preparing preliminary cost estimates. For the most part, the items have been fairly stable over a period of years. In preparing final estimates, actual current costs should of course be obtained.

Unit Operation Costs.

Crushing of limestone, rough crushing on large scale, 10 cts. per ton.

Grinding of cement clinker, 20 cts. to 30 cts. per ton.

Calcining of limestone, $1.25 to $1.75 per ton of lime produced. Cost of roasting ores is about the same.

Leaching 20 per cent of soluble salt from roasted ores with hot water, 20 cts. per ton of ore, or $1.00 per ton of salt.

Separating 20 per cent solution of a salt from reaction magma, using a thickener, $1.00 per ton of salt (equivalent to 10 cts. to 20 cts. per ton of waste solids).

Centrifugal separation of liquor from wet crystals, with washing, 50 cts. to $1.00 per ton of crystal product.

Drying, 50 cts. to $1.00 per ton of dry product.

Evaporation, in single-effect salt evaporator, 60 cts. per ton of water evaporated.

All of the above costs include fixed charges on investment.

Steam and Water Costs.

Steam, 30 cts. per 1,000 lb.

Raw water, 2 cts. per 1,000 gal., including delivery and sewerage.

Filtered water, 10 cts. per 1,000 gal.

Softened water, 40 cts. per 1,000 gal.

Distilled water, $1.20 per 1,000 gal.

All of above costs include fixed charges and 20 per cent return on the investment.

Packing Costs.

Bags, 100-lb. double @ 11 cts., $2.20 per ton.
Bags, 200-lb. double @ 20 cts., $2.00 per ton.
Bags, 200-lb. single @ 15 cts., $1.50 per ton.
Bagging costs (fertilizer) $0.50 per ton.
Drums, 55-gal., I.C.C. 5-E nonreturnable, iron, @ $2.50, or about 5 cts. per gallon, when loaded to 52 gal.

Storage and Handling Costs.

Storage, 5 cts. per hundredweight per month, equivalent to about 20 cts. per drum per month, or $1.00 per ton per month.

Handling, in and out of storage, varies from 5 cts. to 7½ cts. per hundredweight, equivalent to about 20 cts. to 30 cts. per drum, or $1.00 to $1.50 per ton.

City drayage, varies from 10 cts. to 20 cts. per hundredweight, equivalent to 40 cts. to 80 cts. per drum, or $2.00 to $4.00 per ton, depending on size and location of city. Manufacturer's drayage cost, from factory to railroad depot, in truckloads, is about 7 cts. per hundredweight, equivalent to 30 cts. per drum or $1.40 per ton.

All storage, handling, and drayage costs are based on gross weights. Gross weight of drum, when loaded with 52 gal. of alcohol, is about 400 lb.

Labor Cost and General Expense.

For general operating labor, charge 75 cts. per hour, on basis of 8-hr. day and 40-hr. week. For first-class operators and others of comparable skill, charge $1.00 per hour. For common labor charge 50 cts. to 60 cts. per hour.

For works general expense, charge 30 per cent to 40 per cent of the direct labor cost.

Cost of Common Raw Materials.

Coal.—Coal costs vary from about $2.00 per ton at points within short haul ($1.00 freight) to $4.00 to $5.00 per ton in large industrial centers on the Middle Atlantic Coast and on the Great Lakes. For most cost estimates, a cost of $5.00 per ton should be about right.

Coke.—With a coal cost of $4.00 to $5.00 per ton, assuming by-products recovery, the cost of coke will be $6.00 to $8.00 per ton.

Limestone.—The cost of limestone, crushed and screened, varies from about \$2.00 per ton at points within short haul (\$1.00 freight) to \$3.00 in the large industrial centers.

Salt.—In the form of brine, salt costs from 50 cts. to \$1.00 per ton. The corresponding cost of solid salt is about 5 to 10 times as much as the cost in the form of brine; that is, the average differential between brine and solid salt is \$5.00 per ton. In a good location, within short haul of the deposits, solid salt can be purchased for \$5.00 per ton. In locations not so well situated, the cost will be as much as \$10.00 per ton.

Phosphate Rock.—The large users of phosphate rock are located so that their costs are usually within the range of \$5.00 to \$7.00 per ton.

Prices of other raw materials and reagent chemicals are subject to considerable variation; therefore, reference should be made to published price lists, as for example in the *Oil, Paint and Drug Reporter*.

CHAPTER VIII

UTILIZATION OF FUELS AND ENERGY

Strictly speaking, there is no classification of coals for steam, gas, and coke production, but certain properties of coals make them useful for such purposes. Although expediency may dictate the choice of coals, the desirable properties should be known.

Coals for Steam Raising.—In choosing coal for steam making, heating value is the basic characteristic, although the ash content and melting point of the ash are important, as they control clinker formation. According to Demorest,[1] ash fusing at about 2600°F. should not cause clinker troubles; ash fusing between 2300 and 2600°F. is easily controlled; but a fusion temperature of 2200°F. or less may cause trouble, especially with side-fed mechanical stokers. When the ash content is less than 4 or 5 per cent, the fusion point generally ceases to be a factor. The coal itself may be troublesome if it cakes in the distillation zone, thus reducing the draft with simultaneous evolution of excess volatile fractions. In general, low-volatile coals require a large grate area, and high-volatile coals require a large combustion chamber. If a certain type of coal has a marked price advantage, it may be worth while to adapt the furnace and boiler to that type, provided the supply is reasonably permanent.

Producer Coals.—As with coal for steam making, high heating value is desirable for producer coals. Low ash content and high fusibility of ash are especially desirable, as clinker troubles are relatively more serious in gas producers than in the ordinary furnace. For example, a cheap coal may cause excess labor and repair costs, thus offsetting the saving in coal cost. Caking tendencies retard the passage of gas through the fuel bed, thus interfering with operation. The coal purchased should be the

[1] "Coal as an Industrial Fuel," *Chem. Met. Eng.*, **32**, 274 (1925); "Producer Gas as an Industrial Fuel," **31**, 578 (1924); "Blue Water Gas Offers Industrial Fuel Economies," **31**, 887 (1924); "When Can City Gas Be Used for Domestic and Industrial Heating?" **32**, 233 (1925).

one that yields the highest B.t.u. in the gas per unit of total operating expense, provided practical trials prove it suitable. Low sulphur is also desirable in producer coals, as sulphur compounds are harmful in some processes in which the gas is used.

Coking Coals.—In coking coals the desirable qualities are good coking characteristics; that is, the solid residue from carbonization should be sufficiently porous in structure and yet strong mechanically. The ash content should be low, but the melting point of the ash need not be high. For metallurgical use, coking coals must be low in sulphur and in phosphorus. The heating value of the coal is secondary, as a high yield of coke with good properties is the controlling factor. As pointed out by Demorest, few coals have ideal properties; consequently, two or more are generally mixed to give an average volatile content of between 25 to 33 per cent, a hydrogen-oxygen ratio of at least 0.58, ash of not more than 8 per cent, and sulphur not more than 1.25 per cent.

For a more complete discussion of coking coals, the reader is referred to various publications of the U. S. Bureau of Mines.

Gas Coals.—For making coal gas, the available gas is the primary consideration; consequently, coals with high volatile content, from 32 to 39 per cent, are preferred. The ash content should be less than 10 per cent, and preferably less than 8 per cent. Sulphur should be less than 1.25 per cent, and the hydrogen-oxygen ratio should be at least 0.59. Although gas is the principal product, coke, tar, ammonia, and light distillates are joint products which make cheap gas possible. The quality of these joint products, particularly the coke, is therefore of interest, and specifications for gas coals must consider the yield and quality of joint products, as well as of the gas.

Pulverized Coal.—Pulverized coal has many advantages of the gaseous fuels, such as (1) combustion with low excess air, (2) virtually complete combustion of fuel, and (3) extreme flexibility of operation. Coals of every commercial grade, furthermore, have been used successfully in properly designed systems. The chief disadvantages of pulverized coal are the preparation cost and the discharge of a large part of the ash into the atmosphere. Fusion of the ash on the furnace walls may cause trouble also.

The cost of preparation includes crushing, drying, and pulverizing, the object of drying being to remove moisture that would interfere with efficient pulverizing, handling, and combustion. Preparation costs vary widely, depending upon hardness and other physical characteristics, the fineness of the product, size of the plant, and the load factor. Assuming power to be 1 ct. per kilowatt-hour, labor at 50 cts. per hour, a fineness of 82 to 85 per cent through 200-mesh, and operation 23 hrs. per day, 300 days per year, a preparation cost of 45 cts. per ton of bituminous coal has been reported for a 100-ton daily output and about 35 cts. per ton for a 500-ton daily output. Reports from other modern plants of large size indicate that average costs of preparation will range from about 90 cts. per ton in the 100-ton plant to 70 cts. per ton for a 500-ton plant and 60 cts. per ton for a 1,000-ton plant. These are over-all costs and include fixed charges on the investment. There is, of course, a minimum economic size of pulverizing equipment, and for the unit system, in which no storage is provided, this minimum size is about 20 tons daily capacity. The minimum size for storage-system equipment is much larger, between 50 and 100 tons daily capacity.

Pulverized coal has clearly demonstrated its worth in many large-scale operations, such as burning cement clinker, burning lime, smelting copper ores in reverberatory furnaces, and in firing large industrial furnaces for either steam making or heating operations in which ash is not objectionable. The discharge of ash from the stack constitutes a nuisance in thickly populated areas and may lead to litigation. Ash troubles from pulverized coal also prevent the economical operation of recuperative and regenerative equipment, and in fact, any equipment that must be kept free and clean. Recent developments in handling and burning pulverized coal have greatly increased its utility, and in large steam plants, especially, pulverized coal should enjoy wider acceptance.

Fuel Oil.—Industrial oil-burning equipment has been developed to a stage where high efficiencies of atomization and combustion are regularly obtainable. The hazards and operating troubles of many of the first burners are no longer factors in the choice of oil as a fuel.

Oil has advantages over coal that may result in a lower over-all production cost, although the heating cost alone may be more

than with coal. An oil-burning set is readily fired and adjusted to varying loads, and is quickly shut down. Labor costs are lower than with coal, and so are maintenance and repairs. Operating efficiency is high with oil, as it can be burned with very low excess air, and combustion is relatively easy to regulate. Lastly, oil is easy to handle and store and it requires about one-half the storage space required for an equivalent quantity of coal. This is an immense advantage on locomotives and ships, where storage space is at a premium.

Possibly, the strongest objection to fuel oil is the instability of price and the difficulty of making long-time supply contracts. The general upward trend of oil prices, however, is unlikely to be sharp enough to make sudden change of fuel necessary. In plants that burn more than 20 tons of fuel a day, pulverized coal is a real competitor of oil, but in smaller plants oil is considered more economical.

Producer Gas.—Of the industrial gaseous fuels, producer gas is the most widely used, especially for large-scale operations. It is cheaper than any other gas except natural gas, and this factor, combined with ease of control, makes it suitable for many industrial operations, such as lime burning, coke-oven heating, open-hearth-furnace heating and glass-tank heating. Because a properly designed gas producer will convert coal to gas with a higher thermal efficiency than any other equipment, it is applicable to nearly every operation in which gas is required. Producer gas is, therefore, preferable to coal when control of furnace atmosphere, uniform distribution of heat in the furnace, cleanliness, or ease of fuel distribution to many operations is desired. For large-scale plant operations in isolated locations, producer gas is preeminent. The disadvantages are low heating value and low flame temperature. When high temperatures are wanted, recuperators or regenerators must be used. Low heating value is a factor, as oversize gas-handling equipment is required.

Blue Water Gas.—Blue water gas is different from producer gas in that it contains relatively little inert gas, has nearly twice the heating value, and burns with a relatively high flame temperature. The cost of blue water gas in terms of 100,000 B.t.u. is about one and one-half times that of producer gas, but certain properties make it preferable as an industrial fuel. In addition to high flame temperature, blue water gas burns with a clean

flame and has a high efficiency of use. The gas itself is free from soot and tar and, therefore, can be piped at high velocity to remote parts of the plant without clogging the lines.

Coal Gas.—Coal gas is likely to be increasingly important among industrial fuels, not only because it has excellent characteristics, but because the carbonization of raw coals, especially by low-temperature processes, and complete gasification of coal at the mines, appear to be logical developments in the interest of both fuel conservation and low energy cost. Coal gas is the most costly of the common gaseous fuels; but, even at present prices, it could with profit be more widely used industrially. Compared solely on the cost per 100,000 B.t.u., coal gas is more expensive than fuel oil or coal, but the true basis should be the over-all cost of the finished product and not the fuel cost alone. The high fuel efficiency of coal gas, increased output, and greater uniformity of product may far outweigh its greater cost, especially as compared with coal. Other gaseous fuels, such as producer gas and blue water gas, however, are much cheaper than coal gas and may be preferred on a fuel efficiency basis.

Coal gas or mixtures rich in coal gas are available in every industrial center except the natural-gas regions and are good fuels for nearly every heating operation. Rich coal-gas mixtures have about twice the heating value of water gas and more than three times the heating value of producer gas. They have a high flame temperature and a rapid combustion rate. The only serious objection is one of cost. The fixed charges on a city gas plant are high and the stand-by capacity for the winter load is idle during the summer; consequently, a fairly constant and large industrial load is the best hope of reducing over-all costs. Of course, some city gas contains little or no coal gas—a fact not to be overlooked.

Competitive Position of Coal Gas.—Even at present prices, many industries can use coal gas and actually reduce over-all costs of production. Compared solely on the cost per 100,000 B.t.u., coal gas cannot possibly compete with raw coal. Gas can be burned with 75 per cent efficiency, however, as against 30 per cent for coal. The advantages of thermostatic control, reduction in direct labor, extreme flexibility in load and cleanliness, furthermore, may be sufficient to justify coal gas in preference to any

TABLE VII.—COMPARATIVE COST OF HEAT FROM ELECTRICITY AND VARIOUS INDUSTRIAL FUELS (*from Demorest*)

Source of heat	Per cent excess air	B.t.u. value of fuel	Temperature of furnace, degrees Fahrenheit	Price of fuel or electricity	Cost per 100,000 B.t.u.	Per cent heat lost			Cost per 100,000 B.t.u.	
						In flue gas, non-recuperating	Recuperating	By radiation	Without recuperation	With recuperation
	50	12,500	400	$4.00 per ton	$0.016	10.5	....	5	$0.019	.....
Bituminous coal	50	12,500	1600	4.00 per ton	0.016	50.5	....	10	0.041	.....
	50	12,500	2300	4.00 per ton	0.016	75.0	....	15	0.160	.....
	10	535	400	$0.75 per 1,000 cu. ft.	0.140	6.5	....	5	0.158	.....
City gas	10	535	1600	0.75 per 1,000 cu. ft.	0.140	31.0	16.0	10	0.238	$0.185
	10	535	2300	0.75 per 1,000 cu. ft.	0 140	46.5	20.0	15	0.364	0.240
	10	1,100	400	0.50 per 1,000 cu. ft.	0.046	10.7	....	5	0.0545	.....
Natural gas	10	1,100	1600	0.50 per 1,000 cu. ft.	0.046	50.5	27.0	10	0.117	0.073
	10	1,100	2300	0.50 per 1,000 cu. ft.	0.046	76.0	33.0	15	0.510	0.110
	10	300	400	0.30 per 1,000 cu. ft.	0.100	7.0	....	5	0.114	.....
Water gas	10	300	1600	0.30 per 1,000 cu. ft.	0.100	32.0	15.0	10	0.172	0.137
	10	300	2300	0.30 per 1,000 cu. ft.	0.100	51.0	20.0	15	0.293	0.185
	10	150	400	$4.00 per ton coal as gas	0.032	10.5	....	5	0.0380	.....
Producer gas*	10	150	1600	4.00 per ton coal as gas	0.032	50 0	22.0	10	0.0800	0.052
	10	150	2300	4.00 per ton coal as gas	0.032	75.0	37.0	15	0.355	0.068
		3,415 B.t.u.	400	$0.015 per kw.-hr.	0.440	0.0	....	5	0.456	.....
Electricity		per	1600	0.015 per kw.-hr.	0.440	0.0	....	10	0.488	.....
		kw. -hr.	2300	0 015 per kw.-hr.	0.440	0.0	....	15	0.518	.....
	20	135,000 per gallon	400	$0.06 per gallon	0.045	8.5	....	5	0.052	.....
Fuel oil†	20	135,000 per gallon	1600	0.06 per gallon	0.045	43.0	22.0	10	0.096	0.065
	20	135,000 per gallon	2300	0.06 per gallon	0.045	66.0	30.0	15	0.240	0.092

* With 10 per cent by volume of steam in gas.
† Using ⅓ lb. of steam per pound of oil.

other fuel, even oil. When many consumers cease to think of fuel only in terms of cost per 100,000 B.t.u., and base comparisons on over-all production costs instead, coal gas, producer gas, and blue water gas will have wider acceptance.

Processes in which coal gas is used successfully are glass and enamelware manufacture, nonferrous metal melting, heat treating, and carburizing. In each of these processes, high thermal efficiency, exact furnace control, favorable furnace atmosphere, improved working conditions, and increased production are factors that make this gas a profitable fuel, despite the higher cost per 100,000 B.t.u.

For a detailed discussion of fuels, the reader is referred to "Combustion," 3d ed. (1932), American Gas Association.

Comparative Costs of Heating.—The comparative cost of industrial heating, with electricity and various common fuels, is shown in Table VII, which was prepared by Demorest. The table compares the cost of heat based on current or fuel costs only, and does not include handling costs or allowance for the various convenience factors. When current or fuel costs differ from those assumed in the table, the cost of heat per 100,000 B.t.u. is increased or decreased in direct proportion.

Excepting solid fuels, which require handling for both the feed and the ash, and stoker or preparation expense, industrial fuels can be compared fairly accurately as to cost per 100,000 B.t.u. Design of oil and gas burners and furnaces has advanced progressively until convenience and flexibility approximate electric heat. The heat losses shown in Table VII are based on furnace discharge temperatures of 392°F., 1652°F., and 2372°F., and the net cost of heat per 100,000 B.t.u. is shown both with and without recuperative operation assuming an entrance air temperature 60 per cent of that of the furnace exit gases with recuperation.

HEAT RECOVERY AND CONSERVATION

Recovery of heat from furnaces is an important factor in fuel conservation and in improved operation. Common examples are the economizer for recovery of heat from stack gases to preheat boiler feed and waste-heat boilers for the recovery of heat from rotary cement kilns. Several types of equipment are notable because unusually high efficiencies are attained. Among these

are the Hoffman ring furnace, Dietzsch kiln, American Dressler tunnel kiln, and regenerative furnaces.

Heat Recovery in Furnaces.—The Hoffman ring furnace comprises a series of chambers grouped about a central stack. One chamber is active, one is discharging, and one is charging, at any given time. The others are either being cooled by entering air, or preheated by the stack gases. The incoming air is preheated by passage through chambers containing the burned product, which is itself cooled. At the same time, the hot stack gases from the active chamber pass through another set of chambers containing the unburned product, which is thereby preheated.

The Dietzsch kiln is a vertical two-stage shaft kiln in which combustion of the fuel and heating of the admixed charge occur in the lower part, the charge being preheated by the combustion gases as they pass through the upper part. To prevent premature ignition, the fuel is admitted at the beginning of the combustion stage instead of at the top of the kiln.

When operated in countercurrent, rotary kilns afford some recovery of heat; but the efficiency is low, due to poor heat transfer between the solid charge and the combustion gases. Waste-heat boilers in series with the kilns have proved successful in portland cement manufacture.

The American Dressler tunnel kiln is a comparatively recent development in heat recovery. It is divided into two parts, the heating zone and the cooling zone. In the heating zone the charge travels horizontally in countercurrent to hot flue gases, and burning is complete at the end of this zone. In the cooling zone the burned charge is cooled by large pipes that carry the air for combustion, and the preheated air and gaseous fuel meet near the junction of the two zones, where combustion occurs.

In the regenerative system, two pairs of towers packed with brick are operated alternately. While the flue gases give up heat to one pair of towers, the fuel gas and air separately absorb heat from the other pair of towers. Regenerative checkers are essential in iron smelting, as the entrance air must be hot enough to keep the iron molten. The furnace gases preheat the downcoming charge in countercurrent, so that separate regenerative stoves are needed for preheating the air for combustion.

Utilization of Waste Heat in Cement Mills.—Within recent years the utilization of waste heat from cement kilns has made rapid forward strides. The idea of recovering heat from the stack gases of cement kilns is not new. According to Schaffer,[1] the first waste-heat boiler was built in 1897 by I. A. Bachman. This and succeeding boilers were unsatisfactory, owing to the settling of dust in the flues. In 1903 a fairly successful waste-heat boiler was constructed, the dust being removed in settling chambers installed between the kilns and the boilers. With the addition of economizers after the boilers and an induced-draft fan after the economizers, sufficient steam was generated to supply about half the power requirements of the entire plant. Present-day efficiencies, however, are such that an entire cement plant can be operated on power from waste-heat boilers. This economy is the result of three distinct improvements:

1. More efficient design of boilers, whereby practically all the flue dust is removed. High coefficient of heat transfer is obtained between the hot gases and the boiler tubes by lengthening the gas passages and by increasing the velocity of the gases.

2. Reduction in steam requirements of prime movers. Modern turbines and reciprocating engines have been developed with low steam consumption, as compared with practice in 1900.

3. The power consumption of various milling operations has been decreased through improvements in design.

As in all recovery systems, an increased investment is required. For example, the cement manufacturer must invest from $250,000 to $700,000 in a waste-heat plant that generates substantially all the power needed for milling. Ordinarily, the savings will be equivalent to 30 to 50 lb. of coal per barrel of cement. Against this saving in fuel must be balanced the operating costs and fixed charges on the investment.

Heat Insulation.—Engineers in central stations, large industrial power plants, hotels, and office buildings, have long known that insulation pays. Industry in general, however, is just beginning to realize that the same principles apply broadly, including such chemical equipment as evaporators, stills, heat exchangers, dryers, jacketed kettles, and liquid lines, as well as to such power-plant equipment as boilers, engines, and steam lines.

[1] "Waste Heat from Cement Kilns Operates Entire Mill," *Chem. Met. Eng.*, **29**, 18 (1923).

The seriousness of heat losses from bare surfaces has been expressed by Weidlein[1] as follows:

It is recognized generally that the losses from bare pipes and boilers are considerable, but the real magnitude of these losses is little appreciated. The fact that the loss from 1,000 sq. ft. of exposed surface at

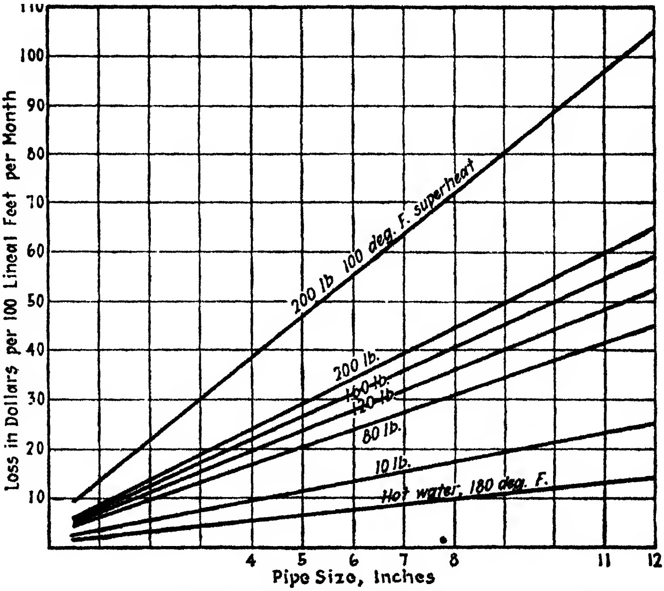

FIG. 36.—Losses from horizontal bare iron steam pipes.
Calculated for 100 lineal feet of pipe per month of 30 days, steam in pipe 24 hr. per day. Coal is assumed to be $5 per ton fired, boiler efficiency 70 per cent, air temperature 70°F. and heating value of coal 13,000 B.t.u. per pound. (*From Heilman.*)

100 lb. per square inch steam pressure represents over 300 tons of coal annually is a sufficient justification for the serious consideration of the subject.

Figure 36 shows the heat losses from bare pipes carrying steam and hot water at different temperatures, as determined by Heilman.[2]

At a certain point the saving will be a maximum, as increased thickness means a proportional increase in fixed charges, which

[1] "Conservation of Heat in Power and Heating Systems," *Chem. Met. Eng.*, **24**, 295 (1921).

[2] "Heat Losses from Bare and Covered Wrought Iron Pipe," *Chem. Met. Eng.*, **27**, 63 (1922).

must be balanced against the heat conserved. The optimum thickness for heat insulation has been determined accurately by Weidlein, and these results are expressed in part in Fig. 37, which shows that for each temperature difference, there is an optimum thickness of lagging.

The proportion of time in which the equipment is in service also should be noted. Obviously, the fixed charges on the equipment

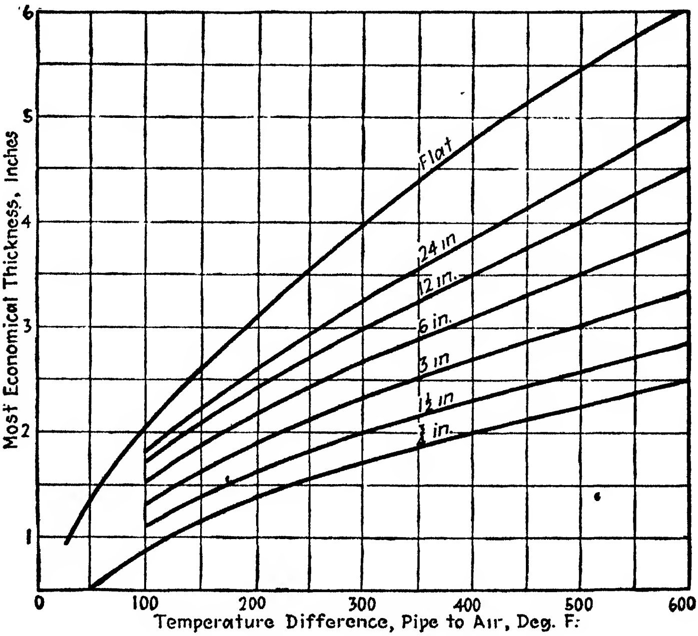

Fig. 37.—Thickness of pipe covering for maximum net saving. Calculated for continuous service and assuming steam to be 60 cts. per 1,000 lb. and fixed charges on covering at 13 per cent. (*From Weidlein.*)

are continuous, whereas the saving in heat occurs only when the equipment is in active service. The investment in insulation, however, will as a rule pay for itself within a year or two. Tests have shown that insulation on a locomotive-type boiler increased the evaporation from 6.35 to 7.55 lb. of water per pound of coal, saving 15 per cent in fuel.

EXHAUST-STEAM UTILIZATION

During recent years chemical engineers have learned how to utilize exhaust steam at comparatively high back pressures, thus

conserving large quantities of heat. The back pressure depends largely upon the process temperature. As the minimum allowable temperature drop in heat-transfer equipment under favorable conditions is 20 Fahrenheit degrees and under average conditions is about 50 Fahrenheit degrees, an appropriate temperature difference is added to the process temperature, in order to determine the required exhaust-steam temperature.

As pointed out by Field,[1] high back pressure can be obtained in the following three ways:

1. By increasing the initial steam pressure.
2. By increasing the cutoff of reciprocating engines.
3. By a suitable combination of increased initial pressure and increased cutoff.

In general, an increase in back pressure will make unnecessary the independent generation of low-pressure steam for heating. When the back pressure is not determined by temperature requirements of the process, the most economical back pressure may be determined by charts that have been constructed by Field. Briefly, the most economical back pressure is determined as follows: The weight of low-pressure steam is divided by the weight of steam consumed by the engine, giving a ratio that corresponds to a definite cutoff. Knowing the initial allowable boiler pressure and the percentage cutoff, the most economical back pressure is read directly from the chart. As the ratio of steam required for heating to that required for power varies considerably in most plants, and as the back pressure will, in general, be constant, the cutoff, and consequently, the efficiency of the engine will vary.

In plants in which the ratio of steam for heating and power is fairly constant, a uniflow engine will be economical. In plants in which the ratio is somewhat variable, a bleeder-type turbine will be more satisfactory, as it is capable of considerable flexibility in operation.

When no heating temperature is specified, the highest permissible back pressure should, in general, be used. As the heat transmitted per square foot per hour per unit thickness of the heating surface varies directly with the temperature drop between the condensing steam and the substance being heated, the advantage of high steam pressure is apparent. Field says:

[1] "Exhaust Steam at High Back Pressures," *Chem. Met. Eng.*, **20**, 18 (1920).

We see, if we assume the case under consideration to be that of evaporating in an open vessel, that at a 50-lb. back pressure a given apparatus would do more than five times the work it would do at a 5-lb. back pressure, and similarly that a 50-lb. back pressure and a given apparatus would do about 70 per cent of the work it would do at a 100-lb. pressure.

High Back Pressure Gives Cheap Power.—The conclusions to be drawn from a study of the three variables—cutoff, initial pressure, and exhaust pressure—are as follows: The greatest saving to be realized from a change from low-pressure to high-pressure exhaust steam will be in those plants in which low-pressure process steam has been generated and in which at the same time electric power has been purchased. In such a plant, an increase in initial boiler pressure will permit the generation of sufficient power, still leaving the exhaust steam with about 85 per cent of its initial total heat and at a pressure sufficient for process purposes. The cost of power under such a plan would be only a fraction of the cost of steam generated, plus the operating expenses and fixed expense of the engine room. As the cost of steam comprises from 50 to 70 per cent of the cost of generating power in plants that operate condensing, the possibilities for saving are large.

Although an increase in boiler pressure increases the total heat in the steam, and therefore the quantity of fuel required per unit weight of steam, experience shows that this increase in cost is negligible. Any increase in fuel cost in a large plant, furthermore, would be offset by the decrease in radiation losses and fixed charges on the steam lines. For example, steam at 50-lb. gage back pressure will require only 24 per cent by weight of the pipe required for steam at 6-lb. gage back pressure. Although the temperature difference between the pipe and the air will be greater at higher pressures, the reduction in surface area will be sufficient to make the total heat losses from radiation less at the higher pressure.

Low-temperature Exhaust Steam for Evaporation.—When the prime movers operate on a low back pressure, the exhaust steam may be useless for process heating because of its low temperature. Under such conditions, about 80 per cent of the original total heat of the steam is dissipated in the condensing water.

In general, engineers have considered that low-temperature exhaust steam is useless. Nickle[1] describes an arrangement whereby the exhaust steam from compound condensing engines has been used profitably. The pressure in this installation was from 2.9 to 7.5 lb. absolute. The plant was designed to concentrate weak caustic effluent from electrolytic cells. Multiple-effect evaporators were considered, but the estimated investment was excessive, and considerable live steam would be necessary for operation. The engines in the power plant were compound condensing units that operated under a vacuum of from 24 to 26 in. of mercury.

In order to utilize this low-temperature exhaust steam, an evaporative condenser was placed in series with the original jet condenser. The evaporative condenser created a partial vacuum and was arranged so that a final condenser would produce sufficient temperature drop to enable the heating coil of the evaporator to perform the necessary work. When the quantity of exhaust steam exceeded that necessary to operate the evaporator, the original jet condenser was cut in, thereby increasing the power from the engines. Although it is true that an evaporative condenser will increase the back pressure on the engine about 2 lb., thus considerably reducing the power developed, yet this is not, as a rule, a controlling factor.

Operating Difficulties in Multiple-effect Evaporation.—In general, the over-all economy of evaporation increases as the number of effects increases, at least until three or four and sometimes five effects are reached. This is true, for example, in the evaporation of sugar and salt solutions and black liquor. A double-effect or triple-effect evaporator for small outputs and a quadruple-effect for large outputs are commonly used.

As Mantius[2] has shown, certain solutions, of which caustic liquor is an example, cause trouble from incrustation of the tubes, corrosive action of the liquor, and from the elevation of the boiling point of the concentrated solution, thus practically eliminating the quadruple-effect evaporator even for large outputs, restricting

[1] "Heating an Evaporator with the Exhaust from Condensing Engines," *Chem. Met. Eng.*, **31**, 226 (1924).

[2] "The Evaporator and the Power Problem in Electrochemical Plants," *Chem. Met. Eng.*, **12**, 722 (1914).

the operation of a triple-effect to certain favorable conditions, and making a double-effect installation the most economical for plants of medium output.

POWER COSTS

Whether to generate power at the plant or purchase it from the central station is perhaps the most common problem confronting the plant engineer. As a rule, the primary generation of electric power by industrial plants is neither profitable nor desirable. Most central stations, particularly the larger ones, can generate power and deliver it to the plant for less than the cost of generation in small quantities and under unfavorable conditions. Even assuming that the industrial plant could have cheap primary power—actually competitive with purchased power—still, it would be better to lose a little money on power bills than to run the risk of interruptions in service. Over a period of years, steam central-station service is extremely reliable, much more so than even the best industrial power plants. Hardly ever does it lose its load and then only for short intervals. Unfortunately, the same cannot be said of hydroelectric stations, as these usually are farther from the consumer of power, and the transmission lines are a vulnerable part of the equipment. Electrical storms, in particular, may cause interruptions of considerable duration and frequency.

When steam is required primarily for process, however, electric power is generated secondarily. Even inefficient industrial power plants can compete successfully with efficient central stations, because most of the heat that the central station dissipates in condensing water is used for process work and heating in the plant. There is about 15 per cent transmission loss, furthermore, between the central station and the plant, and this, of course, is added to the price of power. In good noncondensing operation, about 20 per cent of the total heat of the steam is used by the engines; 40 per cent is absorbed in process equipment; 20 per cent is returned to the boiler as hot condensate; and 20 per cent is lost unavoidably, mostly by radiation.

GENERATED VERSUS PURCHASED POWER

Cost of Power in Industrial Plants.—The cost of power generated by industrial plants depends considerably upon the terminal

steam pressures and the size of operating units. Maynz[1] estimates that, even with the best practice, power cannot be generated in small plants for much less than 1.5 cts. per kilowatt-hour. He assumes a 200-kw. uniflow engine with a water rate of 32 lb. per kilowatt-hour, a steam rate of 8 lb. per pound of coal, or 4 lb. of coal per kilowatt-hour, and a boiler pressure of 150 lb. The fuel cost would be 0.9 ct. per kilowatt-hour, and the total cost of power 1.5 cts. per kilowatt-hour.

In a large industrial unit, a 10,000-kw. condensing turbine operating at 200 lb. and 200 deg. superheat against a 29-in. vacuum, and with a water rate of about 13.5 lb. per kilowatt-hour, about 1.9 lb. of coal would be required per kilowatt-hour. Assuming a plant cost of $180 per kilowatt, fixed charges at 16 per cent, a 50 per cent load factor, the total cost of power would be 1.3 cts. per kilowatt-hour.

From these estimates it is clear that competition with central-station power is not likely to be profitable when power alone is required. When steam is generated for process and heating, however, power can be generated economically as a by-product. Maynz classifies the common arrangements for combined process steam and electric power generation as follows:

1. High-pressure engines or turbines exhausting into process mains.
2. Bleeder or extraction turbines.
3. Low-pressure or mixed-pressure turbines using process exhaust.

When high-pressure engines or turbines are used, exhausting at a back pressure of from 35 to 100 lb. gage, the conversion of thermal energy in the steam to mechanical energy is very efficient. The steam usually is exhausted with a superheat. Under these conditions, about 4,000 B.t.u. is required per kilowatt-hour; whereas, very few central stations approach 18,000 B.t.u. per kilowatt-hour.

In bleeder or extraction turbines, which operate condensing, the steam for process is bled automatically from intermediate stages. Excess steam passes to the low-pressure stages and then to the condenser. The by-product electricity is obtained at low cost, and the over-all efficiency is high.

[1] "Electric Power as a By-product of Process Steam Generation," *Chem. Met. Eng.*, **32**, 5 (1925).

In the mixed-pressure turbine, steam is expanded from about atmospheric pressure to as high a vacuum as is feasible, usually between 28 and 29 in. Although a large part of the electricity can be generated from this low-pressure steam, some high-pressure steam must be bled into the high-pressure stages, in order to correct fluctuations in the exhaust-steam supply.

TABLE VIII.—COST OF POWER WITH NONCONDENSING UNIFLOW ENGINE, ASSUMING VARIABLE STEAM DEMAND FOR HEATING (*from Maynz*)

Heating and power costs:		
Coal cost at $4.00 per ton	$12,000	
Water	100	
Labor	8,600	
Supplies (for engine and equipment)	1,200	
Fixed charges (for engine and equipment)	3,000	$24,900
Heating costs:		
Coal cost at $4.00 per ton	$ 7,000	
Water	25	
Labor	2,200	
Supplies		
Fixed charges		
Total		9,225
Additional cost of power		$15,675
Cost of power per kilowatt-hour		1.63 cts.

Noncondensing Engine Operation.—Maynz cites the following example of noncondensing uniflow engine operation in an industrial plant:

Working hours, 18 hr. per day, or	5,100 hr. per year
Energy requirements, 170 kw. demand	960,000 kw.-hr. energy
Heating requirements (no power)	26,300,000 lb. steam
Operating pressure	150 lb. gage
Steam consumption (noncondensing)	32 lb. per kilowatt-hour

The engine operates at 150 lb. pressure and 32 lb. per kilowatt-hour, exhausting into the heating mains during the winter and exhausting to the atmosphere in the summer. Maynz says:

To produce the 960,000 kw.-hr. will require 30,700,000 lb. of steam, to which must be added 1,800,000 lb. for operation of pumps and auxiliaries, or a total of 32,500,000 lb. of steam for engine operation. An analysis shows that 11,000,000 lb. additional steam is required for heating the building during the cold months and at night. The stand-by loss and banking coal is 100 tons per year. The total coal requirements at 7½ lb. evaporation per pound of coal is 3.000 tons. The credit for

heating to produce the 26,300,000 lb. required when no power is made, is 1,750 tons of coal, leaving a net coal consumption of 1,250 tons of coal directly chargeable to power production.

Analysis of the problem shows that by using the exhaust steam for heating, power is produced at a fuel cost of about 0.5 ct. per kilowatt-hour, assuming coal at $4.00 per ton, and charging to power production 1.6 lb. per kilowatt-hour. Additional labor and supplies are required for the engine room; furthermore, the fixed charges on the engine room equipment add considerably to the total cost, as is shown in Table VIII.

TABLE IX.—COST OF POWER WITH NONCONDENSING UNIFLOW ENGINE, ASSUMING UNIFORM PROCESS STEAM DEMAND (*from Maynz*)

	No engine	With engine
Total steam required:		
Heating, pounds	26,300,000	26,300,000
Process, pounds	25,500,000	25,500,000
Used in making electric energy	....	4,700,000
Total, pounds	51,800,000	56,500,000
Coal at 7½ lb. evaporation, tons	3,450	3,760
Stand-by and banking, tons	100	100
	3,550	3,860
Coal cost at $4.00 per ton	$14,200	$15,440
Labor cost	5,000	8,600
Miscellaneous supplies and repairs	....	800
Fixed charges on engine equipment	....	3,000
Total cost per year	$19,200	$27,840
Additional cost of power	....	8,640
Total cost per kilowatt-hour	....	0.9 ct.

Assuming central-station power at $1.50 per kilowatt-hour demand, and 1.3 cts. per kilowatt-hour of energy, the total cost of power if purchased would be $1,295 per month, or 1.62 cts. per kilowatt-hour. Consequently, the independent generation of power would not be a profitable venture under these conditions.

If, however, in addition to its heating load the plant had a process load of 5,000 lb. of steam per hour and 1 lb. gage throughout the year, all power would be by-product. The problem under

the new condition is shown in Table IX and is analyzed by Maynz as follows:

> This shows that by the absorption of all the steam from the engine in heat and process and the requirements of firing labor and boilers in operation throughout the year for the process steam, the additional labor for the two engineers, and the additional supplies and repairs for the engines have been reduced considerably, and the manufacture of power would show a net saving of about $7,000 per year above the cost of purchased power, or a net return of 28 per cent (after all charges) on the $25,000 additional capital required.

Load Factor.—When electric power is purchased, a knowledge of how the power bill is computed will aid in effecting savings. If large quantities of power are purchased, the savings may be surprisingly large. The essential condition for maximum economy is a high load factor, which will be attained only when the average demand is fairly uniform and does not deviate markedly from the maximum demand.

As the power company must at all times be prepared to furnish the maximum demand, it must sell at a premium the current that is much above the average demand, in order to make a fair operating profit. Hence, power at high load factor will cost much less than the same quantity used at low load factor, and this is the way to reduce power bills without reducing the quantity of current consumed.

First of all, the load should be plotted for a period of operation that includes every situation in ordinary production. If the resulting curve is fairly flat, then the load factor is high, and little can be accomplished by changing the operating schedule. More likely, the curve will show fluctuations in demand, often as much as several hundred per cent. The demand charge, as it is called, may constitute from one-quarter to three-quarters of the total power bill, depending upon the load factor, therefore eliminating the peaks in demand is the next step in the investigation. Study of the causes of the peaks and valleys in the load curve will usually reveal a situation that can be improved. Scheduling of processes to avoid the simultaneous operation or idleness of many big units will tend to flatten the load curve and, consequently, to reduce the maximum demand. In general, the larger the plant, the easier it is to distribute the load evenly.

An example cited by Risley[1] shows how a power bill was reduced from $791 to $536 merely by changing the maximum demand. The manufacture of a certain product comprised several processes, one of which required only ¾ hr. but was a heavy consumer of power. The three machines on this process were operated simultaneously, giving a high peak load. A study of the situation showed that the process could be changed so that the three machines could be run on a staggered schedule. The maximum demand was thereby reduced from 125 units to 40 units. The power contract did not contain a separate demand charge, as this was included in the current cost. The rates were 6 cts. per unit for the first 50-hr. use of the maximum demand; 4 cts. per unit for the next 50-hr. use of the maximum demand; 2 cts. per unit for the rest. Under the new method, 6 cts. per unit had to be paid on 50 times 40 units, or 2,000 units instead of 50 times 125, or 6,250 units, as before. Thus, for the same power consumption, the new method required fewer units at the higher rate and more at the lower rate, as follows:

Before Changing		After Changing	
6,250 @ $0.06 =	$375	2,000 @ $0.06 =	$120
6,250 @ 0.04 =	250	2,000 @ 0.04 =	80
8,300 @ 0.02 =	166	16,800 @ 0.02 =	336
20,800	$791	20,800	$536
Average per unit, $0.038		Average per unit, $0.026	

This reduction in power cost was obtained entirely by reducing the maximum demand.

[1] "Decreasing Maximum Demand Lessens Power Cost," *Chem. Met. Eng.*, **32**, 391 (1925).

CHAPTER IX

OPERATION AND CONTROL

Since individual efficiency always has been an important factor in production costs, much attention was devoted to wage systems even in the early days of scientific management. Among the older contributions of permanent value were "Gain Sharing," by H. R. Towne (1889); "A Piece Rate System," by F. W. Taylor (1895); "A Bonus System for Rewarding Labor," by H. L. Gantt (1901); and "Shop Management," by F. W. Taylor (1903).

Taylor's Contribution to Management.—Taylor's paper of 1903 was the first inclusive exposition of scientific management. It was the result of nearly a quarter century of research. The four basic principles of industrial management outlined by Taylor are:

1. Classification of all information relating to the industry and systematic research in the processes of manufacture.
2. Selection of workers for their tasks according to talent and skill.
3. Training and supervision of workers through functional foremanship.
4. Assumption by the management of responsibility for the foregoing activities.

Taylor is known particularly for his development of functional control. The idea underlying functional control is that industry requires the services of specialized supervision. For example, in a large machine shop the following specialists would be required:

1. Order-of-work or route clerk.
2. Instruction-card clerk.
3. Time-and-cost clerk.
4. Gang boss.
5. Speed boss.
6. Inspector.
7. Repair boss.
8. Shop disciplinarian.

Each of these specialists has authority in his function throughout the shop, and each worker is subject to contact with all of

them. Contrast this with line control, in which a foreman has authority in all functions over a single group of workers, and each worker has contact with only one foreman. The modern industrial organization exemplifies the best features of both systems. This is illustrated by the organization descriptions given in Chap. II.

As scientific management originated in the mechanical process industries, the question has been raised whether these principles apply to the chemical process industries. The answer is that Taylor's concepts are fundamental to all types of industry, although the details of organization and control necessarily vary from one industry to another.

Importance of the Basic Technology.—In the chemical process industries, technology is the important consideration. Consequently, the major problems in the chemical industries relate to the efficient utilization of energy, materials, and plant. Therefore, the first of Taylor's four principles—classification of all information relating to the industry and systematic research into processes of manufacture—applies with particular force.

Recognition of the essentiality of research has created for France, Germany, Great Britain, Italy, and Japan strong chemical industries, even in the face of inferior natural resources. In this country, managements have not so generally regarded the technical organization as a training school for operation, sales, and general management, in addition to its basic technical function.

In the mechanical process industries, a large proportion of production cost is for labor on such operations as casting, forging, welding, drawing, grinding, machining, pressing, stamping, finishing, and assembling. Consequently, these operations, in which manual skill plays so important a part, have long been studied by management engineers; but in the chemical process industries, the field of research shifts to materials and energy. Baumeister[1] says:

> Scientific research is the foundation of chemical industry; on it all else depends. The aim of the research must be the cheapest possible production of the largest possible quantity of product of the desired quality. Economy of time, labor, power, and materials; uniformly high efficiency and quality of product are the factors sought.

[1] "Fitting Scientific Management to Chemical Industry," *Chem. Met. Eng.*, **32**, 551 (1925).

Responsibility of the Chemical Engineer.—Under scientific management, high standards of performance are set, but the attainment of these standards is not demanded until a favorable working environment has been created. Upon the chemical engineer more than upon anyone else falls the responsibility of maintaining a high level of operating efficiency. He must do more than produce a satisfactory product. Through scientific control the chemical engineer must attain maximum economy of materials, supplies, energy, and equipment. Groggins[1] states the essential requirements of sound, economical operation as follows (the discussion under each heading being the author's):

1. *Determination of inherently best production methods.* For example, if anhydrous ammonia is desired, the direct synthesis from hydrogen and nitrogen is inherently a better method than the reaction of calcium cyanamid and steam.

2. *Selection of best type and most economical size of equipment.* For example, for handling large volumes of free-filtering slurry, a rotary continuous filter might be selected, rather than a filter press.

3. *Attainment of highest practicable yields.* The highest attainable yield is not necessarily the most desirable from the economic viewpoint. For example, in a batch distillation process, it was found that the cost of the operation at 98 per cent yield was double the cost at 92 per cent yield. The material was so cheap that the maximum profit on the operation was attained at a point far below the maximum yield. An economic balance, therefore, should be worked out for each operation, in order to find the yield which corresponds to the minimum cost (full cost plus normal return on the investment, plus material loss).

4. *Continuity of operation and maximum productivity per unit of operating time.* Continuity of operation represents an ideal which, although not always completely attainable, usually can be approached by making one or more of the constituent unit operations continuous. Thus, Walker, Lewis, and McAdams[2] say:

> Continuity of operation offers such obvious and marked advantages that it is used wherever practicable; but in many cases continuity can

[1] "Aniline and Its Derivatives," D. Van Nostrand Company, Inc., New York (1924).

[2] "Principles of Chemical Engineering," McGraw-Hill Book Company, Inc., New York (1937).

only be approximated, giving rise to semi-continuous operations, as in the intermittent firing and cleaning of a hand-fired boiler, the operation of a "ring" furnace, the manipulation of the leaching tanks in the extraction of black ash or tan bark, the charging of a blast furnace and the like. When the character of the operation is essentially intermittent, continuity is often approached by the combination of a number of units operating simultaneously but in different stages, as in the coking of coal in byproduct ovens and the recovery of waste heat in regenerative chambers of refractory checker work; (*e.g.*, blast-furnace stoves).

5. *Purchase of raw materials at favorable prices.* Consideration of this factor may go further than the purchase of raw materials at favorable prices in relation to existing sources of supply. It may be desirable to develop and encourage new sources of supply.

6. *Minimum of overhead expense.* In any operation, there is an irreducible minimum overhead expense representing the smallest skeleton organization of administration, sales, production, and research with which its business can be conducted. Beyond this point, production can be increased without increasing the overhead expense in direct proportion. Therefore, the operation, if conducted independently, must be reasonably large, in order to secure the advantage of low overhead expense per unit of output. Obviously, the way to secure low overhead at the start is to consolidate the new operation with an existing operation.

Of the foregoing factors, the chemical engineer is particularly influential in determining the first four. He should be equally alert, however, to sense the way to better practice relative to the other factors.

Elements of Scientific Production Control.—Richards[1] enumerates the following elements of scientific control in production:

1. Weights.
2. Compositions.
3. Volumes.
4. Pressures.
5. Thermometry.
6. Calorimetry.

Weights.—The use of scales to measure quantities of raw material and yields and to regulate the charging or discharging of a furnace or other equipment is so nearly universal that it is difficult to imagine the chemical engineer doing any work without

[1] "Rule of Thumb vs. Engineering," *Electrochem. Met. Eng.*, **5**, 4 (1907).

them. In general, however, scales are not used enough or with sufficient care. Too little attention is accorded detail. For example, the coal to be fed to a boiler is placed in storage and the amount used each week is accurately known; but if the weight taken from storage were determined for each shift of firemen and compared night and day, or day by day, relative efficiencies could be determined. Extravagances may go on for years if not controlled by careful weighing, carried out in sufficient detail and for each operating unit. The cost of obtaining this information invariably will be repaid several times by the better control thereby made possible.

Compositions.—Richards once said that the greatest benefactors of chemical engineering and applied chemistry were those, such as Berzelius and Fresenius, who developed analytical chemistry into a practical art, and those, such as Bell, Bessemer, Lunge, and Muspratt, who led in its industrial application. The analytical chemist is essential in controlling many industrial operations. Although he is primarily a routine worker, he soon acquires such intimate insight into plant operations that he may become a logical candidate for positions of greater responsibility.

The modern way to get scientific control of quality is to use the chemist with his methods of examination—analytical, microscopic, experimental—and so keep going a works laboratory. If it does not pay for itself several times over it will be through human imperfections in the laboratory staff or in the management of the works, but not through defects in the principle involved.

In any but the large plant, the chemist will do the work of the physicist also, making the physical measurements of volumes, pressures, temperatures, and heat balances which are much needed but too little employed. Usually, by education and practical experience, he is better fitted to do this work than is the mechanical engineer, to whom such tasks are often assigned.

Volumes.—The use of instruments to measure the volume of gases or liquids is an improvement over rule-of-thumb and is an important step toward accurate control. The Pitot tube, orifice meter, Venturi meter, and draft gage are a few of the instruments of broad general usefulness. Such instruments as water meters and steam meters can be obtained in both the indicating and integrating types, the records from which form an accurate basis for process control and cost accounting.

Pressures.—Pressure is another important operating variable. Pressure gages are far more generally used than other types of measuring instruments. A reason for this is the realization by the operator of the correlation between pressure and personal safety. Precise control of pressure is essential in such operations as ammonia synthesis, petroleum cracking, and pulp cooking.

Thermometry.—Thermometry indicates the intensity of heat. Hardly any other variable is so important as temperature, and the only reliable method of control is through instruments. Recording thermometers and pyrometers have done much to remove empiricism and to transfer responsibility for control from the workmen to the management.

Calorimetry.—Calorimetry is the science of measuring quantities of heat and is essential in determining efficiencies of equipment, such as steam boilers, heat engines, condensers, heat exchangers, dryers, and evaporators.

Technical Control in Practice.—As has been pointed out by Moore,[1] many chemical and metallurgical operations are carried out by men who have had no formal training in technology. Through long experience, however, the operator may develop sufficient skill to enable him to operate successfully a process, even though it is complicated by many variables. There is grave danger in this situation. If the operations so conducted are vital ones in production, a few men can, if they so desire, exert undue pressure on the management. Moore says:

> I have seen the time when six men not only had the power, but exerted it, to shut down the largest mill of its kind in the world. Realizing this fact, they made the most exorbitant and unscrupulous demands. Here, again, had the management possessed the information which the men had obtained, this thing would have been impossible.

The remedy lies in plotting every operation according to the best known experience. For example, in cooking chips in the sulphite process, it is possible to control the "cook" from data obtained on large-scale tests. When properly plotted, these data constitute a graph that can be used as a process control by the workmen. Supplementing this graph is a table of pressures corresponding to the temperatures of steam. Moore says:

[1] "The Human Element in the Mill," *Chem. Met. Eng.*, **19**, 146 (1918).

When we first started this system, we found it very difficult to make the men understand that a pressure below atmospheric pressure was a real pressure, so we plot these pressures below atmospheric pressure as minus pressures, and a table of the pressures corresponding to temperatures of steam is given to every cook. Thus 158°F. would show as pressure on this chart as -10 lb., while 250°F. would show as $+15$ lb. Now the gage pressure is plotted, and the steam pressure corresponding to the temperature is also plotted. The difference between these two is the gas pressure, which is also plotted. Then, inasmuch as it is the sulphur dioxide gas which does the cooking, this picture shows the cook if he is blowing off the gas too fast . . . The cooks are taught to plot these charts themselves, and in so doing they correct their cooking procedure. Having established the value of the chart, we were in a position to demand uniformity of results. This example is an illustration of how the management formerly expected too much of the men, when they asked for greater uniformity of results than they got.

This chart has another value in that it is now possible to do experimental work in the laboratory and draw the desired chart which we may reasonably expect the cooks to duplicate in practice.

Production Control in the Beet-sugar Industry.—One of the pioneers and leaders in scientific production control is the beet-sugar industry. About 1895, a group of European beet-sugar manufacturers established a central cooperative bureau for analyzing their production data. As the result of similar efforts in the domestic industry, the price of sugar in the New York wholesale market decreased from 15.53 cts. in 1870 to 4.28 cts. per pound in 1913.

Sugar costs are figured in terms of tenths of a mill per pound. As the larger beet-sugar companies have an annual production exceeding 600,000,000 lb., one-tenth of 1 mill per pound is equivalent to $60,000. Thus, the necessity for rigid technical control is apparent.

The detail in which operation is controlled is illustrated by the report shown in Table X, concerning which Zitkowski[1] says:

In form, these reports will vary more or less among the different sugar companies, though in substance practically the same data are compiled by all. This is the final criterion of the technical operating results and is compiled and calculated from literally dozens of various agricultural, factory-station, laboratory and supply warehouse reports, to go into

[1] *Chem. Met. Eng.*, **31**, 103 (1924).

the detail of which would be entirely beyond the scope of any one paper. Each item on this report is a problem in itself.

Consider for a moment the first item on this report, "Beets Received." The plant pays the grower of beets on the basis of the sugar content of the beets delivered by him, with the result that each load, as delivered, is sampled, and occasionally as many as 1,000 samples per day are received for analysis. The problem here begins with the proper and correct sampling of the load. Individual beets vary widely in sugar content, even though they were neighbors in the field, so that it becomes a real problem to obtain a representative sample under all conditions. Sugar is not uniformly distributed in the beet itself, so that a further problem is involved in obtaining an aliquot portion from each beet in the sample for analysis. The most practical and efficient method of determining the sugar content in beets under all conditions is still a subject for discussion, although it is prescribed by law in at least one state.

Referring again to the report, it will be observed that this gives the quantities of the various products and materials of importance in the process, both for the last operating day and to date, expressed in terms of per cent on beets and in terms of per cent on sugar entered. Thus, it presents a comprehensive and continuous picture of the operating results. With this before him and carrying these results daily with results obtained in previous years or at other plants, the superintendent can readily determine the weakness of his operations and can concentrate on these.

Illustrating the possible improvement in the efficiency to be effected by control, Zitkowski has prepared Table XI, which shows the comparative slicing capacity and sugar extraction in two plants over a period of 33 years. In factory *A*, the average extraction of sugar increased from 51.52 per cent in 1891–1892 to 88.98 per cent in the year 1923–1924. Even in factory *B*, which is a much larger and more efficient plant, the extraction increased from 82.49 per cent in the year 1899–1900 to 97.43 per cent in the year 1923–1924. Indicating how this increase in extraction efficiency affects profits, Zitkowski says:

Factory *B*, during several of its operating seasons, has introduced more than 100,000,000 lb. of sugar; a difference of 1 per cent in the extraction means 1,000,000 lb. of sugar at 5 cts. per pound, worth $50,000 for each per cent. The extraction of factory *B* during recent years has been more than 10 per cent above the results of the early years of its life, and 10 per cent means $500,000 worth of additional sugar recovered per season. This shows the possibilities and rewards of a closer technical control and increasing efficiency.

TABLE X.—DAILY OPERATING REPORT OF A TYPICAL AMERICAN BEET-SUGAR PLANT (*from Zitkowski*)
(*B* factory, eighty-seventh day, from 6 a.m. Oct. 28 to 6 a.m. Oct. 29, 1920)

	Last 24 hr., tons	To date, tons	Daily average, tons	Last 24 hr.			To date			Days yet to operate
				Percentage, sugar	Purity	Percentage, tare	Percentage, sugar	Purity	Percentage, tare	
Beets received	655	226,099	2,600	19.42	81.2	3.95	18.82	80.6	3.80	..
Beets sliced	1,691.605	222,103.709	2,552.9	18.68	80.7	....	18.76	80.4	....	4
Bags sugar	7,585	802,447	9,227							
Bags dried pulp	2,038	224,224	....							
Bags molasses pulp	....	38,831	....							
Total bags pulp	....	263,055	3,024							
Tons crude potash	8.310	1,089.166	12.52							

		Last 24 hr.			To date		
		Total tons	Percentage on beets	Percentage on sugar entered	Total tons	Percentage on beets	Percentage on sugar entered
1	Total sugar entered	315.992	18.68	100.00	41,671.118	18.76	100.00
2	Sugar in pulp	1.692	0.10	0.54	247.831	0.11	0.59
3	Sugar in waste water	0.677	0.04	0.21	87.945	0.04	0.21
4	Sugar in lime cake	2.768	0.16	0.87	199.942	0.09	0.48
5	Sugar in Steffen waste water from	4.704	0.28	1.49	332.186	0.15	0.80
6	Total known losses	9.831	0.58	3.11	867.904	0.39	2.08
7	Sugar bagged	379.250	22.42	120.08	40,122.350	18.07	96.28
8	Sugar estimated in process (granulated equivalent)	....	....	.....	100.000	0.05	0.24
9	Sugar melted bought or from previous campaign (granulated equivalent)	....	....	.....	89.826	0.04	0.22
10	Net extraction	....	....	.....	40,132.524	18.08	96.30
	Molasses statement						
11	Sugar in molasses produced	135.087	7.98	42.76	10,832.217	4.88	26.00
12	Sugar in molasses worked in Steffen	135.087	7.98	42.76	10,832.217	4.88	26.00
13	Total sugar in molasses to pulp plant	....	....	.....	236 942	0.11	0.57
14	Wet molasses produced	257.800	15.24	81.57	21,315.800	9.60	51.18
15	Wet molasses worked in Steffen	257.800	15.24	81.57	21,315.800	9.60	51.18
16	Total wet molasses to pulp plant	....	....	.....	442.658	0.20	1.06
17	Steffen extraction, per cent	....	96.57	.....	....	96.98	.....
18	Steffen waste produced per cent wet molasses worked	2,240–869 %	....	.....	197,501–926 %	.....	.....
	Pulp statement						
19	Dried pulp bagged	101.900	6.02	32.24	11,211.200	5.04	26.90
20	Molasses pulp bagged per cent molasses day to date	....	....	.....	1,941.550	0.87	4.66
21	Total pulp bagged	....	....	.....	13,152.750	5.91	31.56
22	Pounds fuel oil to 100 lb. dried pulp produced	....	35.5	.....	....	38.0	.....
	Material statement			Percentage on sugar extracted			Percentage on sugar extracted
23	Lime entered in carbonations (slaked and powder)	129.798	7.67	34.22	11,507.197	5.18	28.6

No.	Item	Last 24 hr.	To date						
24	Total lime used			129.798	7.67	34.22	11,507.197	5.18	28.68
25	Lime entering coolers to 100 lb. sugar in molasses worked			129.798	96.1	.....	11,038.048	101.9	.....
26	Vertical lime produced			126.408	7.47	33.33	10,152.945	4.57	25.29
27	Vertical waste per cent vertical product			....	....	.....	100.806	0.99	.....
28	Rotary lime produced from lime cake			20.741	1.23	5.47	1,752.689	0.79	4.37
29	Spall lime produced from spalls			15.001	0.89	3.98	639.647	0.29	1.59
30	Rotary lime used per cent total lime used			20.741	15.99	.....	1,752.689	15.24	.....
31	Spall lime used per cent total lime used			15.101	11.64	.....	639.647	5.56	.....
	Fuel oil	Last 24 hr.	To date						
32	B. H. factory	1,397.3 bbl.	125,993.0 bbl.	227.421	13.45	81.44	20,505.474	9.24	51.10
33	B. H. potash manufacture	153.2	16,190.0	24.933	1.47	6.57	2,664.958	1.20	6.64
34	B. H. total	1,550.5	142,183.0	252.354	14.92	8.01	23,170.432	10.44	57.74
35	Pulp plant	228.8	31,591.8	36.150	2.14	9.53	4,993.027	2.25	12.45
36	Rotary kilns	60.2	5,005.4	9.798	0.58	2.58	814.040	0.37	2.03
37	Spall kiln	32.2	1,353 3	5.240	0.31	1.38	220.791	0 10	0.55
38	Total fuel used	1,871.7	180,133.8	303.542	17.95	101.50	29,198.290	13.16	72.77
39	Cold water	14,000,000 gal.	1,253,000,000 gal.	....	3,452	.....	....	2,353	.....
40	Boiler feed water			3,944.5	233.1	.....	345,656.0	155.7	.....
41	Lime rock			202.450	11.97	53.39	18,333.800	8.26	45.68
42	Lime rock as spalls			28.510	1.69	7.52	1.227 500	0 55	3.06
43	Coke			23.980	1.42	6.32	2,110.935	0.95	5 26
44	Sulphur			0.887	0.05	0.23	80.239	0.04	0.20
45	Soda to juices			4.850	0.29	1.28	423.400	0.19	0.06
46	Total soda used			5.100	0.30	1.35	449.493	0.20	1.12
47	Kieselguhr			1.222	0.07	0.32	110.215	0.05	0.27
48	Wash water used on carbonation filters			910	Percentage on cake	109	94,737	Percentage on cake	148
49	Wash water used on cold saccharate filters			....	Percentage on cake	....	....	Percentage on cake	......

	Diffusion batteries						Pans													
							Last 24 hr.							To date						
									Apparent purity						Apparent purity					
	Number in operation	Number cells in operation	Tons per cell	Per cent, dil.	Per cent draft by weight	Time of diffusion	Quality	Number	Fill mass	Green	Total drop	Theoretical yield	Hours in crystallizer	Number	Fill mass	Green	Total drop	Theoretical yield	Hours in crystallizer
Today	2	20	6.1	54	150	1 hr. 44 min.	Str.	10	84.2	70.2	14	56	....	1076	84.1	71	13.1	54	....
To date	......	......	6.1	54	158	1 hr. 36 min.	Raw	9	72.4	56.1	16.3	51	32	507	71.5	55.2	16.3	51	44

Battery extraction; sugar in diffusion juice today 312 tons, 98.1 per cent on sugar entered. To date 41,296,99.1 per cent on sugar entered. Temperature; battery maximum 80°C. Average before lime, 90°C. Before first filter, 90°C. Before first refilter, 93°C. Before second filter, 101°C. Finished cooler, 18°C. Hot saccharate, 86°C. Leaving thickener, 84°C.

TABLE XI.—COMPARATIVE SLICING CAPACITY AND SUGAR EXTRACTION IN TWO PLANTS OVER A PERIOD OF 33 YEARS (*from Zitkowski*)

Year	Factory *A*		Factory *B*	
	Average daily slicing, tons	Average extraction of sugar, per cent	Average daily slicing, tons	Average extraction of sugar, per cent
1891–1892	178	51.52	.....	.....
1892–1893	234	67.03	.....	.....
1893–1894	214	62.16	.....	.....
1894–1895	Not operating	.....	.....	.....
1895–1896	267	59.95	.....	.....
1896–1897	348	64.74	.....	.....
1897–1898	357	64.78	.....	.....
1898–1899	294	71 33	.....	.....
1899–1900	251	71.40	1,193	82 49
1900–1901	Not operating	.....	1,044	81.92
1901–1902	Not operating	.....	1,418	82 67
1902–1903	318	79.20	1,420	89 37
1903–1904	337	80.50	1,432	83 23
1904–1905	367	78 56	1,696	85 30
1905–1906	323	77 07	1,498	87 86
1906–1907	306	78.68	1,650	85 82
1907–1908	333	75 48	1,643	90.52
1908–1909	362	68 76	1,744	89.63
1909–1910	283	66.55	2,142	90 38
1910–1911	364	73.40	2,600	90.30
1911–1912	394	70 12	2,657	90.12
1912–1913	395	73.81	2,443	93.93
1913–1914	412	71 61	2,406	90.82
1914–1915	400	74 42	2,822	90 04
1915–1916	441	75.20	2,715	92.86
1916–1917	430	72.92	2,602	95.25
1917–1918	427	73.61	2,327	92.82
1918–1919	468	87.61	2,035	96.02
1919–1920	444	86.46	2,096	97.30
1920–1921	468	86.52	2,536	97.29
1921–1922	510	88 93	2,780	97.13
1922–1923	496	90.15	1,170	97.01
1923–1924	533	88.98	1,600	97.43

Contributing principally to this marked advance in operating efficiency, which is characteristic of many industries other than the one just cited, has been chemical engineering. Increased extraction and increased evaporative efficiency have resulted in decreased steam consumption. The efficiency of steam generation itself has increased. Despite the enormous increase in wages, the direct labor cost per unit of product has decreased substantially. During the early years of the industry, from 6 to 8 factory labor-hours were required to produce 100 lb. of sugar. A figure of 29 min. of operating labor per 100 lb. of sugar has been recorded in a large western plant. During the past 50 years the wholesale price of sugar has decreased about 70 per cent, while at the same time the important items of operating cost, such as raw materials, labor, and fuel have increased, on the average, at least 200 per cent.

Position of the Technical Staff.—So diverse are the problems of chemical industry that cooperative effort is absolutely essential. It is, therefore, wise to select men of widely varying technical accomplishments, so that the organization will be well balanced. As Weidlein[1] says:

> No research man is a complete unit of himself. He requires the contact, the stimulus and the driving power that are generated by his association with other research men, in his own organization as well as at meetings of professional societies.

In selecting men, the characteristics and needs of the industry will have considerable weight. For example, the proportion of the staff skilled in organic chemistry should be greater in the dyestuffs industry than in the heavy chemicals industry. In the large organization, however, specialists in all branches of applied chemistry and chemical engineering can be employed effectively.

Frequently, a research problem will originate in a customer's plant, the contact being through the technical service staff, and these externally originating problems are likely to be different from production problems. For example, in the petroleum refining industry, large sums are spent on the study of combustion of liquid fuels and on the fundamentals of lubrication, problems that originate with the customer. Consequently, the technical staff

[1] "The Administration of Industrial Research," *Ind. Eng. Chem.*, **18**, 98 (1926).

of the petroleum refinery requires specialists not only in organic and physical chemistry, distillation, absorption, and heat transfer; but in combustion, engine design, and lubrication.

For a detailed exposition of specific functions of the technical organization, reference should be made to the books by Weiss and Downs and by Mees and to the many excellent articles in American, British, and German journals.

Support of General Executives Essential.—As pointed out by Weidlein, an essential condition for successful technical work is the right attitude on the part of company executives.

> Prior to establishing an industrial research laboratory in their organization, the company executives should believe in the realizable possibilities of research, should intend to give it proper financial and moral support, should know what to expect from it, should have determined whether to try a comprehensive and thorough type of research or to limit the work to a narrower study of specific problems as they arise, and should be prepared to give sufficient time to put the laboratory well on a sound basis. The laboratory director, if properly chosen—and great care is needed in selecting him—can be relied upon to do the rest, but he should be aided in launching the work correctly, and in maintaining suitable facilities and staff for attending to all scientific research of the company.

A common administrative error is to expect too much of a technical organization and to regard as useless and wasteful any program that is not aimed at results of immediate money value. It is safe to say, however, that no other business activity yields so much return per dollar as does continuous, well-directed technical effort. Whatever the problem or its outcome, something worth while is certain to be gained, and in a surprising number of instances financial success attends to research that is begun primarily to extend the fundamental knowledge. Steinmetz once remarked that the whole character of the transmission equipment business was changed by an apparently abstract investigation that was started by the General Electric Company on the properties of the electric corona. Nieuwland's academic research on derivatives of acetylene was the basis of later work leading to neoprene chloroprene rubber. By no means are these isolated examples. The executive should be slow to scorn an effort from which there is no apparent immediate benefit.

Operating Rate versus Profits.—Although most cost estimates are based on the assumption that operation will be 100 per cent of capacity, in practice the operating rate usually is considerably below full capacity. How seriously a decline in operating rate affects profits, even though selling price remains the same—which it usually does not—is shown in Table XII.

At full capacity, the indicated net profit is $7.81 per ton, which corresponds to a return of 17 per cent on the total investment.

TABLE XII.—RELATION OF OPERATING RATE TO PROFITS

Basic assumptions:		
Capacity, 340,000 tons per year		Per ton
Plant investment	$10,200,000	$30.00
Average working capital	5,100,000	15.00
Total capital	$15,300,000	$45.00
Annual sales	$10,200,000	$30.00
Depreciation @ 7%, taxes and insurance @ 1½% of plant investment	$ 867,000	$ 2.55
Works general charges @ 30% of labor	204,000	0.60
Total operating overhead	$ 1,071,000	$ 3.15
Selling expense @ 1½%, research expense @ 1½%, and general administrative expense @ 3% of sales, total	$ 612,000	$ 1.80

Operating results:		Per ton	
Per cent of capacity	100	50	25
Mill cost exclusive of overhead	$17.24	$18.42	$20.78
Operating overhead	3.15	6.30	12.60
	$20.39	$24.72	$33.38
Selling, research, and general administrative expense	1.80	3.60	7.20
	$22.19	$28.32	$40.58
Selling price	30.00	30.00	30.00
Net profit	$ 7.81	$ 1.68	L$10.58

At 50 per cent capacity, however, the indicated net profit is only $1.68 per ton, which corresponds to a return of only 2 per cent on the total investment. At 25 per cent capacity there is an indicated net loss of $10.58 per ton, which corresponds to a total loss of $899,300 on 85,000 tons output per year. The point of "break-even" operation is, therefore, just under 50 per cent of capacity.

The question sometimes arises; Why operate at a loss? As the figures of Table XII indicate, even if the plant were shut down completely, and the entire staff dismissed—which would, of

course, be impracticable—the fixed charges would be $867,000 per year, or only slightly less than the operating loss at the 25 per cent operating rate. It is, therefore, usually advantageous to keep a plant in operation, even though a substantial loss is shown. There are other reasons, however, why a plant virtually must keep running, no matter how great the loss: (1) Such custom as remains, must be taken care of, otherwise the business would vanish altogether; (2) years are required to build up an efficient operating staff, and it is highly desirable to maintain the staff, at least in a skeleton form; (3) idle plant depreciates with alarming rapidity.

Supply and Demand.—As is well known, when the demand for a commodity exceeds the supply, prices go up and vice versa. Thus, the prices of agricultural commodities, metals, and minerals exhibit at times violent fluctuations, since the supply is not readily adjustable to the demand over a period between seasons, or within the time necessary to bring new facilities into production.

Chemical prices, however, are relatively stable, and, even though the demand trend be increasing, chemical prices tend to decrease. The reason for this is that the advantages of large-scale mass production and improved technology come into play as demand increases. Some of the resulting decreases in price with increased demand are no less than astonishing. For example, the price of "Cellophane" cellulose film decreased from $2.65 a pound in 1924 to 41 cts. a pound in 1936. Between 1927 and 1937, the volume of the moistureproof grade increased nearly fiftyfold. The price of 150-denier viscose rayon yarn decreased from $2.00 a pound in 1926 to less than 60 cts. a pound in 1937; during the same period, the volume increased about fivefold. The price of phthalic anhydride decreased from approximately $1.00 a pound in 1919 to less than 15 cts. a pound in 1936, during which period the volume increased from several hundred thousand pounds a year to 30 million pounds a year.

CHAPTER X

SALES DEVELOPMENT AND SALES

To an increasing extent, research is being applied as an instrumentality of selling, particularly to increase sales by developing new uses and new techniques of use. Research of this kind differs from research as applied to process or product development only in the objectives. Just as much ingenuity and skill is needed for the one kind as for the other. The emphasis on sales development is increasing, and effective procedures have been formulated.

The first step is to secure an abundance of working information concerning the product. Socrates' exhortation, "Know thyself!" can be paraphrased to fit sales development, "Know thy product!" This means acquiring an exact, comprehensive, thorough knowledge. Such knowledge is the foundation of sales development.

Usually the description of the product should exceed the scope and detail of handbook data. Moreover, it is not always advisable to use handbook data in the description of the commercial product. The published data may not be correct; and if correct, may not apply to the particular commercial product. For example, if a solvent is offered to the trade, the actual boiling range should be stated, rather than boiling point or boiling range data from a handbook. Likewise, the trade will be interested in such data as specific gravity, vapor pressure, and viscosity over a considerable range of temperature; heats of vaporization; miscibilities with common liquids; solubilities of various solids; limits of various impurities; flash point; explosive limits with air; toxicity; shipping regulations; shipping containers; price schedule.

The second step is to correlate the properties of the product with uses, securing such patent protection as seems desirable before offering the material or a particular application to the trade. Following are examples in which properties have been correlated with new uses:

1. Methanol has low molecular weight, is completely miscible with water, and its water solutions have low viscosity, high specific heat, and are relatively inert to metals, rubber, and oils. The refined synthetic methanol, therefore, is well adapted for use in automobile antifreeze compositions.

2. A synthetic wax having an extremely high melting point is useful as a constituent of candles.

3. Ammonia, being readily handled as a gas, is an excellent neutralizing agent for the acids which form on the condensing side of petroleum-distillation equipment.

4. Urea is extremely rich in nitrogen, is soluble in water, yet does not leach readily from the soil. Moreover, the reaction of urea in the soil is virtually neutral as compared with the extremely alkaline reaction of nitrate of soda, or the extremely acid reaction of sulphate of ammonia. Urea, therefore, is well adapted for use as a fertilizer.

5. Certain high-boiling monohydric alcohols are extremely surface active in aqueous systems. Accordingly, these alcohols are useful as foam inhibitors.

The third step is to test the proposed uses in the laboratory, taking care, however, to simulate operating conditions as well as possible. During this stage, a large proportion of suggested uses will be found impracticable. The promising uses will be investigated further—on a semi-works or "wash-tub" scale, as distinguished from the test-tube scale.

The fourth step is to induce someone in the trade with whom friendly relations have been established, to test the proposed use in the factory. This step, however, should not be undertaken until the outlook for success is fairly certain or—to state it another way—that, in the event of failure, the chances are slight that serious damage will be incurred.

The fifth and last step is to prepare an operating manual containing all information needed by the trade and by the technical sales representative. The new product, or the new application of the old product is then on a commercial basis.

If the sales development is based on a new product, extreme care is required to ensure that the product can be reproduced with reasonable uniformity. It is axiomatic that, in many operations, a particular impurity is not so harmful as are variations thereof. This means that the production staff must appreciate

fully the nature of the sales-development problem. It is particularly important that the commercial stock be of as good a quality as the sample material, or better.

The easiest approach to a new-product sales-development problem is to advertise that the product is available. Inquiries are then followed up with samples and descriptive material, trusting that the trade will do the rest. Rarely, however, is such an approach sufficient.

The trade reaction is most complete and prompt when the new product or application is backed up with enthusiasm and energy. Apathy on the part of the seller at any stage of the sales introduction is readily detected by the trade and is the surest way to establish a resistance, not only for that particular instance, but for subsequent effort. Much sales development fails because the initial effort is not followed through with the type of service that the trade has a right to expect. It is astonishing how many new products are put out before a thorough knowledge of properties is in hand, or before the seller is prepared to supply trial material and assist the trade technically.

Technical Publicity.—When a product, process, or application has been developed to the point where it is ready for market, a publicity plan should be formulated. Publicity may be regarded as the first step, the basic step, in marketing; the campaign of paid advertising is the second step; and personal salesmanship is the third and final step.

Among technical men it is generally agreed that the first step in the publicity should be a presentation of the development in the technical press, or before a technical society. There are several reasons for this procedure. First, a new industrial product, process, or application usually must be approved by technical representatives of the buyer; second, even if the product is to be marketed direct to the general public, the marketing campaign is much strengthened if based on publication satisfactory to the profession or trade; third, at least one professional society (American Institute of Chemical Engineers) requires in its code of ethics that initial disclosures be made to a technical audience.

As an example, assume that a company has developed a synthetic resin. The process has been worked out on a laboratory scale and on a semi-works scale. A full-scale process and plant

design have been projected on paper. Cost estimates have been made for various outputs. Important physical and chemical properties have been determined. Patents have been secured or applied for, covering various compositions of matter, various methods of making the product, novel features of apparatus, and such uses as have been reduced to practice and seem to have potential importance. A trade-mark has been selected and found to be registrable. Prices have been estimated. A quantity of the material, in various forms and grades, is available for sample distribution.

The company is now ready to make an announcement. This takes the form of a paper for publication in a medium of recognized standing; or better yet, a paper for presentation before a technical society, with subsequent publication. For obvious reasons, the paper should be signed by the person or persons closely identified with the development.

If the development looks as though it would be limited to a few important but unspectacular industrial uses, no attempt at general publicity would be made. For instance, if the resin is to be used in a protective coating for storage tanks, it is of little or no interest to the general public, at least in advance of some tremendously wide use. On the other hand, if the resin is to be used in safety glass, in aircraft construction, in making finishes for automobiles, then the man in the street is concerned and, therefore, is interested. He would like to read about it in his newspaper and in his news magazine. For this purpose, a press release is prepared, embodying the important elements of general interest. It is publishable as soon as the basic paper has been published or presented, not before.

The basic paper and general publicity may then be followed up by such secondary efforts as distribution of reprints of the basic paper; preparation of direct-mail advertising, pamphlets, and periodical advertising copy; and preparation of further articles in the technical and trade press, featuring some special property or application of the product.

By this time, if the publicity has been at all successful, inquiries from prospective users and others should be in hand. These inquiries will call for samples, further technical details, and further details of marketing, such as price, delivery, and grades. This brings up for discussion an important point: If practicable,

the announcement of the new development should be deferred until the company is prepared to follow through properly with the inquiries. Otherwise the trade, as well as the public, will believe that it has been deceived; that the publicity was merely for the sake of publicity—in brief, a stunt. It cannot be stressed too strongly that, in the long run, the publicity cannot be better than the product or policy upon which it is based.

It should be stressed also that the planning, preparation, and supervision of the publicity is in itself a technical matter to be entrusted to qualified persons. Today, among media for technical publicity—properly interpreted—there are not only newspapers and news magazines, but the popular science publications, the motion picture "shorts" and newsreels, the radio, the exhibits in museums and in expositions. Moreover, the newspapers and press associations are vastly better staffed to interpret science and technology than was the case even 10 years ago. The technique of the interview—illustrated with news photographs—has been further developed. The public wants, and is getting, the news of science and of new products.

Technical Advertising.—Broadly defined, any printed, spoken, or exhibited notice of a subject is publicity. This would include advertising. In this discussion, however, an arbitrary distinction is drawn: When the publicity is secured by purchase, it is called advertising. A distinction also can be drawn on an editorial basis; if the subject of the publicity is novel and of interest to the public, or to an important group of the public, it is considered to be "news." Accordingly, an editor might print it as part of the news or editorial content of his paper. Once it has been printed, however, it is no longer news, and any restatement would be secured only in the advertising (purchased) content of the paper. For instance, assume that a rayon has been developed based on cornstalk cellulose, instead of the conventional wood pulp and cotton linters cellulose. This would be news, and an article announcing the development would be printed by a large number—probably a majority—of the country's important newspapers, news magazines, and chemical journals. The rayon manufacturer wanting to keep the subject alive would do so by releasing additional information and by repeating the published information in purchased space. In brief, he would follow up the news with a campaign of paid advertising.

Realizing this distinction between advertising and news, the seeker of publicity habitually will not attempt to secure "free advertising." In fact, no editor who has his readers' interests truly at heart will accord it.

The technique of advertising is, moreover, different from the technique of news presentation. Thus, the advertising message may pointedly direct attention toward a specific product in order to solicit custom.

There is further opportunity for the technical writer in such work as preparing product bulletins, operating manuals, catalogues, and sales letters. In all these things, high standards of scientific accuracy are essential. There is no reason why technical advertising cannot have "sales appeal" and yet be accurate and informative.

Technical Sales.—The notion that selling is a function quite apart from technology does not hold in chemical industry. Few indeed are the chemical products which can be sold and "kept sold" without benefit of applied science. For example, when a new dyestuff is developed, it is necessary to show the consumers (manufacturers of textiles, paper, leather, inks) exactly how to apply the dyestuff, and to inform him exactly how it may be expected to stand up in service. Therefore, not only does the dyestuffs manufacturer maintain a technical sales laboratory, but many of his salesmen and sales executives are likely to be chemically trained. Thus, the "Technical Laboratory" of the du Pont Company's Dyestuffs Division comprises a large number of research chemists, technicians, and assistants. This laboratory is quite distinct from another laboratory devoted to dyestuffs development and manufacture.

Similar organization and procedure exist in other branches of chemical industry. For example, the rubber manufacturer is instructed in the use of vulcanization accelerators, antioxidants, and colors, and in the use of synthetic rubber. The petroleum refiner is instructed in the use of ammonia for neutralizing the acid formed by hydrolysis during distillation. The fertilizer manufacturer is instructed in the use of nitrogenous constituents for mixed fertilizer. Thus, chemical technologists may devote their talents to sales as well as to process development and to production.

The technical sales work falls into three main groups: (1) Sales development, whereby new uses are developed; (2) sales service, whereby customers are instructed in the approved practice of existing uses; and (3) trouble shooting, whereby complaints are adjusted. These three types of technical sales work can be illustrated by the history of a product now widely used in the fertilizer mixing industry, "Urea-Ammonia Liquor."

The product, which is essentially a crude solution of urea in ammonia and water, was demonstrated in the laboratory and in a semi-works mixing plant. Tank-car lots of the liquor were then used by a limited number of fertilizer manufacturers under the close observation and supervision of technical men representing both buyer and seller. Such factors as rate of mixing, temperature of mixing, and concentration of various constituents were studied, and limits were established. This step having been mastered, the product was ready for general sale to the fertilizer industry.

Under the established operating conditions, each new customer was instructed thoroughly in such matters as the unloading of the tank cars; storage of the liquor; the mixing operation; storage of the mixed product; and analytical control. Pamphlets were prepared, covering fertilizer mixing practice, also the agronomic aspects of formulas containing the new product. Such activities come under the heading of sales service.

As an example of trouble shooting, the following is cited. A customer complained that the final mixed goods as made by the recommended procedure was too dry and dusty. It was found that this condition arose because the base superphosphate was much drier than average. Naturally, the final product contained correspondingly lower moisture. A dilution factor was established, in order that the final moisture should be exactly as desired. This trouble shooting was done by the seller's technical service man, in cooperation with the buyer's plant superintendent and chemist.

Purity of Product.—Purity of product is a matter for careful consideration. Much depends upon the use or uses of the product; upon the cost of attaining a specified purity; and upon the nature of the impurities. A few examples will indicate the effect of such factors.

Fertilizer Chemicals.—In the fertilizer art, considerable anxiety has been caused by the use of products of too great purity. As is well known to agronomists, normal plant life requires that a broad range of mineral constituents be present in the soil. Although the soil is normally most deficient with respect to nitrogen, phosphorus, and potassium, it is not so widely recognized that calcium, magnesium, iron, manganese, sulphur, iodine, copper, and other elements also are essential. Thus, the old-fashioned superphosphate has been much maligned because it contains only 16 to 20 per cent P_2O_5 as compared with the concentrated phosphate salts carrying two to three times as much P_2O_5. However, the alleged "waste" in superphosphate is largely calcium, sulphur, and iron. Furthermore, because superphosphate is so easy to use and so cheap to produce, it finds a definite place in the agricultural economy. This is only one of several examples in which diluents or impurities are in fact desirable.

Methanol.—For such purposes as making formaldehyde and dimethyl aniline, methanol of high purity is required. Even for use in automotive antifreeze, the methanol should be extremely pure, free particularly from water insolubles, acids, and oils that have no sensible antifreeze effect.

On the other hand, for certain other purposes, the impurities associated with some grades of wood methanol are desirable. For example, for softening nitrocellulose plastic sheets, methanol that contains acetone and other ketones is superior to pure methanol.

Hydrogen Gas.—A large use for hydrogen gas is in the ammonia synthesis. The hydrogen must be highly pure with respect to such catalyst poisons as carbon monoxide and sulphur compounds; otherwise, the catalyst cost and other costs would be intolerable. Therefore, the way to make cheap ammonia is to use highly pure synthesis gas, which, of course, yields pure ammonia.

Specifications of Purity.—In general, it is just as important (if not more so) that impurities be kept uniform, as that they be kept extremely low. The intelligent buyer of chemicals will determine for each process the maximum tolerance of impurities, so that, instead of blindly insisting upon the highest possible purity, he ascertains whether considerable impurities might be tolerated, with consequent saving in price.

Selling Expense and General Expense.—In response to a request for suggestions regarding points that might be discussed in this revision of "Chemical Engineering Economics," the following statement was received from a chemical engineer who has attained distinction in teaching, in research, and in industrial administration:

> A particular annoyance is cost estimates ground out by research workers who have had no industrial experience and who ignore a great number of cost elements. These persons seem oblivious to the fact that it costs money to sell goods, deliver goods, finance inventories, render technical service, hire lawyers, prosecute patent cases, pay high development and introduction costs, and face a tremendous amount of research expense in order to improve process, product, and to stay in business. A chemist should know better than anyone else that it costs money to stay in the chemical business, as well as to get into it. It never seems to occur to some of these people that these costs are a necessary, normal part of the over-all cost of any chemical enterprise, and if provision is not made to include them, it is only a matter of time when the sheriff will perch on the doorstep.

Analysis of several examples will bear out the wisdom of the foregoing statement. The first example relates to the operating results of a business during the calendar year 1936. This business serves as a good case study, because it comprises both organic and inorganic operations; sales to both industrial and "consumer" markets; sales of large units of staple chemicals, as well as of small units of specialty products. The figures, which represent fairly well a cross section of chemical industry, are shown in Table XIII.

TABLE XIII.—ANALYSIS OF OPERATING COST

		Per Million Dollars of Gross Sales
Gross sales		$1,000,000
Full factory cost		625,000
Freight and delivery expense		48,000
Selling expense		44,000
General administrative expense		35,000
Net profit from operations		248,000
Total investment		$2,075,000
Return on investment	11.9%	
Annual turnover of investment	48.0%	
Ratio of production to capacity	100.0	
Ratio of sales to capacity	87.0	

The following points should be noted: Although the business operated at full capacity, and sales were 87 per cent of capacity, sales were at the rate of only $1,000,000 compared with an investment of $2,075,000; that is, more than $2.00 of capital was required in order to sell $1.00 of product. This high ratio of capital to sales is a characteristic of chemical industry, as is pointed out elsewhere in this book. Therefore, what appears to be a high rate of profit, namely 24.8 per cent of sales, actually is only a fair return on the investment, namely, 11.9 per cent.

TABLE XIV.—ANALYSIS OF DISTRIBUTION COST

	Cents per dollar of retail sales	Per Cent of manufacturer's selling price
Full factory cost:		
Product in bulk	14.0	33.3
Containers	9.4	22.4
Selling expense:		
Advertising	5.8	13.8
Other selling expense	3.2	7.6
General administrative expense	1.4	3.3
Freight and delivery expense	4.0	9.5
Net profit to manufacturer	4.2	10.0
Manufacturer's selling price	42.0	100.0
Wholesaler's gross profit	12.0	
Wholesaler's selling price	54.0	
Dealer's gross profit	46.0	
Dealer's selling price	100.0	

For this particular business, the year 1936 was a good year. By comparison, the same business showed a profit of 19.5 per cent of sales and 8.6 per cent on the investment in the calendar year 1935, when the ratio of production to capacity was 80.6 per cent and the ratio of sales to capacity was 79.8 per cent. In the calendar year 1932, when the ratio of operation and sales to capacity was approximately 50 per cent, the business barely "broke even."

Although the three expense items, "freight and delivery," "general administrative," and "selling," may not appear espe-

cially important, since the total is only 12.7 per cent of sales, it is more revealing to note that the total of these expenses is 51 per cent of the net profit during a good year.

Although not shown in the tabulation, the expense for chemical and engineering research was about 3 per cent of sales, and the expense for advertising was about 2 per cent of sales. These ratios are given merely to indicate an order of magnitude for a particular example. For a type of business in which sales are wholly to industry, the ratio of advertising to sales might be less than 1 per cent; whereas, if sales were wholly to the consumer trade, the ratio might be 5 per cent or more.

The second example relates to a chemical specialty that is consumed by the public in substantial volume. The various items entering into the cost of distribution are shown in Table XIV.

This example is typical of many products that are produced in bulk in large quantity at low cost and which are marketed to hundreds of thousands, even millions, of consumers, in small packages ranging from a few ounces to several pounds.

To the casual analyst, such figures represent a veritable bonanza. He might conclude that there are tremendous attractions in a business in which the factory cost of a product in bulk is only 14 per cent of the price at retail. Actually, each of the three principals in the chain of distribution—the manufacturer, the wholesaler, and the retailer—does well if 10 per cent net profit on sales is achieved. In this example, the factory cost is unusually low, owing to a large volume created through nation-wide sales.

The wholesaler, in turn, maintains a warehouse, to which the manufacturer ships in carload lots of 40,000 pounds. Out of his gross margin of 12 cts., 2 cts. is expended for warehousing and delivery; from 2 to 4 cts. for selling and local advertising; and from 1 to 2 cts. for general expenses, thus leaving an average of 5.5 cts. or about 10 per cent net profit on his selling price.

The retailer has a margin of 46 cts. The expenses and risks, however, are commensurate. He buys in lots of 200 pounds to 2,000 pounds, and the expense of handling in the store is considerable. The displays, sales demonstrations, and local advertising must be carefully planned and executed, else no custom will materialize. Then, in order to make a sale of from 2 pounds to 20 pounds requires from as little as one minute to as much as

15 minutes. The staff of a small retail establishment must be prepared to render the instant service that is demanded by the American public, therefore the cost of an individual sale may be tremendously high. Besides the usual sales presentation, there are the sales service and delivery; and if the sale is not for cash, there are bookkeeping, credit and collection expense, and the possibility of bad debts. The retailer also bears the risk of unsold goods, and of a certain proportion of returned goods from dissatisfied custom. He, too, considers himself fortunate to clear, on the average, 10 per cent on his comparatively modest volume of total sales.

In the example just cited, the competition is particularly severe, not only among the ten or so large producers, but among the hundreds of wholesalers, and the thousands of retailers, many of whom inevitably are competitors. Thus, it is quite evident that profits, and hence prices, are at reasonably low levels.

Ratio of Sales to Capital Investment.—A "yardstick" commonly used by management is the ratio of sales to capital investment. This is known as the turnover ratio. This yardstick is not an absolute unit of measure, but varies according to the type of industry. Within any industry, however, there is a ratio which can be used as a fairly accurate measure of performance. For instance, during the year 1935 a leading public utility operating company had an average investment of $4.50 per dollar of sales. The turnover ratio was therefore 0.22. This same company made 20 cts. net profit per dollar of sales—offhand a handsome profit. Yet the rate of return on the investment, which is the real significant factor, was only 4.5 per cent.

In the same year 1935 a leading meat packing company had an average investment of 30 cts. per dollar of sales. The net profit per dollar of sales was only 2 cts.—offhand, a slim profit. Yet the rate of return on the investment was 6.7 per cent, or 50 per cent greater than that achieved by the public-utility company. In this case, the turnover ratio was 3.33.

A leading manufacturer of automobiles, engines, and other mass-production mechanical products had an average investment of 83 cts. per dollar of sales. The net profit was 15 cts. per dollar of sales, equivalent to 18 per cent return on the investment. The turnover ratio was 1.20.

A leading manufacturer of diversified chemicals and allied products had an average investment of $1.80 per dollar of sales. The net profit was 18 cts. per dollar of sales, equivalent to 10 per cent return on the investment. The turnover ratio was 0.56. These data are summarized in Table XV.

TABLE XV.—SALES AND CAPITAL INVESTMENT (*Results for Calendar Year 1935*)

Items	Public utility operating	Diversified chemicals	Automobiles and machinery	Meat packing
Capital investment per dollar of sales	$4.50	$1.80	$0.83	$0.30
Turnover factor	0.22	0.56	1.20	3.33
Net profit per dollar of sales	0.20	0.18	0.15	0.02
Rate of return on capital investment (per cent)	4.5	10	18	6.7
Ratio of fixed investment to total investment	93:100	70:100	65:100	39:100

For the purpose of making these comparisons, the year 1935 was selected because it was neither a "boom" year nor a depression year. The turnover ratios are extremely significant, and they are representative ratios. Thus, a company in the utilities operating industry, including such branches as gas, power, and light; telephone and telegraph; and rail transportation normally will have an investment of $4.00 or $5.00 per dollar of sales (gross income). Moreover, the ratio of plant investment to working capital is extremely high, so that during times of depressed business, such fixed charges as depreciation, taxes, and insurance become a serious burden.

In the chemical industry the investment is normally $1.50 to $2.00 per dollar of sales. This is a high investment compared with all manufacturing industry, for which the investment is $1.00 or less per dollar of sales. Working capital is an appreciable proportion of the total capital investment.

The meat packing industry is cited, merely to show the wide variations in turnover ratio. Thus, the meat packing company turned over its capital 15 times as fast as the public utility

company. It can operate, therefore, on a slim net profit margin on sales and yet show a satisfactory return on the investment. The meat packer has a high turnover ratio, because a large part of his capital is livestock and meats which are converted quickly into salable products.

Turnover ratio is of interest to a management because it is a means of comparing the performance of similar industrial units. Other factors being equal, a higher turnover ratio means a higher over-all profit. Some causes of subnormal turnover ratio are,

1. Plant operating at less than capacity (a general condition during depression).
2. Idle equipment in certain departments ("bottlenecks" in capacity).
3. Obsolete or inefficient equipment (inability to secure satisfactory output).
4. Shutdowns (due to such causes as floods, strikes, power failure).
5. Excess working capital (too much inventory; too much accounts receivable; too much cash).
6. Overvaluation of assets (inflated assets items).
7. Sharp decline in prices (physical volume of production may remain normal, but dollar volume of sales may fall).

CHAPTER XI

COST ACCOUNTING

Through cost accounts, correctly and accurately assembled and intelligently interpreted, losses and inefficient practices can be detected and stopped; unprofitable products revealed and profitable ones substituted; and business projected into the future.

Originally the simplest kind of record keeping, cost accounting has developed coincident with the increasing complexity of business until it has attained professional status. Industrial cost accounting, though consistent with general accounting principles, has become highly specialized and represents the engineering as well as the accounting point of view. Many engineers have chosen cost accounting as a specialty and have contributed liberally to its advancement.[1]

Cost accounting procedures can be classified as follows:

1. Job method.
2. Unit operation method.
3. Process method.

Job Costs.—The job method has wide application in the mechanical process industries, where costs frequently are charged to individual jobs, or orders, as for example, the production of a special machine or structure. This method has relatively little application in chemical process industries, in which the operations usually are continuous or are repetitions of batch operations.

Unit Operation Costs.—The unit operation method is applicable to a degree to all chemical process industries. It depends on the breakdown of the manufacturing process into definite steps, or unit operations, the individual cost of which can be determined. The method is especially useful when the process comprises a sequence of clearly defined chemical engineering unit operations. For example, in portland cement manufacture, the unit operations

[1] See, for example, "Accounting and Cost Finding for the Chemical Industries," by G. A. Prochazka, McGraw-Hill Book Company, Inc., New York (1928).

of mixing, grinding the raw material, burning, cooling, and grinding the clinker are readily separable. Accurate costs can be obtained on each of these operations.

Costing by the unit operation method permits excellent control, since any marked variation in total cost can be traced easily to a specific operation or department. Moreover, this method facilitates cost reduction, since the most opportune points for attack are plainly revealed. Estimates of cost for new processes likewise are facilitated, since the cost of any desired sequence of operations is obtained readily by reference to unit costs of similar existing operations.

Process Costs.—The process cost method is generally applicable to processes in which the reactions or operations are not readily separable. It represents the over-all cost of a series of operations. The manufacture of intermediates and dyestuffs illustrates the general field of the process cost method.

Study may indicate that some combination of the unit operation cost and process cost methods is desirable. A workable plan, especially for small plants, is to rely on process costs for the routine data, reconciling these with periodic surveys or "audits" of the more important constituent unit operation costs. This will give a check on departmental performance and disclose possibilities for cost reduction. The production of simple and useful control records at minimum expense and with the least interference with production routine is the mark of a good cost system.

Classification of Costs.—Irrespective of the accounting procedure, costs can be classified broadly into the following groups:

1. Direct raw material.
2. Direct labor.
3. Overhead.

By common consent, the sum of direct raw-material cost and direct labor cost is known as the prime cost, and the sum of all three groups is known as production cost (production cost sometimes is called "mill cost"). Direct raw material comprises material actually entering the product. For example, in making sulphate of ammonia by the neutralization process, ammonia and sulphuric acid comprise the direct raw materials. Likewise, direct labor is labor expended on the actual making of the product. In this example, the operators assigned to the neutralizers, centrifugals, dryers, bagging machines, and storage comprise direct labor.

Overhead is superimposed on prime cost and comprises the following charges:

1. Material not entering directly into the product.
2. Labor not expended directly on the product.
3. Service charges.
4. Fixed charges on the invested capital.

Using again as an illustration the manufacture of sulphate of ammonia, indirect material would comprise fuel, water, oil, and miscellaneous supplies. Indirect labor would include foremen, control chemists, mechanics, and other service personnel. Service charges comprise such items as power, heat, light, compressed air, and process steam. Fixed charges comprise interest, rent, depreciation, insurance, and taxes.

The following outline of the elements of production cost could, with slight changes, be adapted to any of the chemical process industries:

- **Production cost.**
  - 1. Direct material.
    - All ingredients entering into the product.
  - 2. Direct labor.
    - *a.* Operators.
    - *b.* Helpers.
  - 3. Overhead.
    - *a.* Indirect material.
      1. Fuel.
      2. Water.
      3. Oil.
      4. Miscellaneous supplies.
    - *b.* Indirect labor.
      1. Superintendents.
      2. Foremen.
      3. Control chemists.
      4. Mechanics.
      5. Maintenance men.
      6. Cost clerks.
      7. Timekeepers.
      8. Watchmen.
      9. Stores clerks.
      10. General laborers.
    - *c.* Service charges.
      1. Power.
      2. Heat.
      3. Light.
      4. Compressed air.
      5. Process steam.
    - *d.* Fixed charges.
      1. Interest.
      2. Rent.
      3. Depreciation.
      4. Insurance.
      5. Taxes.

The ideal statement of production cost is the one in which every item of expense is assigned to a specific order, operation, process, or department. Undistributed expense is the bane of cost accounting. Neglect of this principle is, perhaps, the greatest source of confusion in cost accounting. Detailed study of the factory operations will show which of the cost elements can be distributed accurately and which must be prorated on some arbitrary basis.

After the manufacturing process is studied and the elements of cost are decided upon, the next step is to choose suitable cost bases, in order that the production cost can be expressed in appropriate units of measure, as pounds, tons, or gallons.

Selection of Cost Bases.—Seldom can the same basis be used throughout the entire cost statement. In the beet sugar industry, for example, the ton is used consistently to express the quantities of raw material, material in process, and the finished product. In portland cement manufacture, several bases are used. The raw-material cost (limestone and clay) and the cost of grinding are based on tons. The cost of clinker, however, is based on barrels, and so is the finished product. In a power plant, the cost of pulverizing coal is based on tons; the cost of making steam is based on thousands of pounds; and the cost of electricity is based on kilowatt-hours. Intermediate cost bases permit a more detailed analysis of the process than is afforded by over-all costs.

Measuring Direct Material.—The first step in cost finding is to record the operating data. The value of subsequent reports rests upon accuracy in this part of the work. Direct raw material is

TABLE XVI.—DIRECT RAW-MATERIAL REPORT FOR SMALL-SCALE MURIATIC ACID AND SALT CAKE MANUFACTURE

1. Weight of salt (95 per cent NaCl) used . . . .
2. Weight of oil of vitriol (93 per cent H_2SO_4) used . . . .
3. Theoretical quantity muriatic acid obtained from salt . . . .
4. Actual quantity muriatic acid obtained from salt . . . .
5. Plant efficiency or yield $\frac{(100)(\text{No. } 4)}{\text{No. } (3)}$ . . . .

recorded by weighing or otherwise measuring the material, the quantities being entered on a form similar to Table XVI, which is designed for small-scale muriatic acid and salt cake manufacture. On this same form are recorded the analyses of the raw materials

and also the plant efficiency or yield figure. A simultaneous record made by the stores clerk will show a disbursement of salt and sulphuric acid to the acid and salt cake department.

If the process is operated on a fairly large scale, say 50,000 lb. or 25 tons of product per day, the mechanical problems of measurement are entirely different, although the principles remain the same. In Table XVII, which was designed by

TABLE XVII.—DIRECT RAW-MATERIAL REPORT FOR LARGE-SCALE MURIATIC ACID AND SALT CAKE MANUFACTURE

Period ending............

Consumption of raw materials:

Salt (95 per cent NaCl)............	Oil of vitriol (93 per cent H_2SO_4)...
Stock last report..................	Stock last report..................
Shipments received................	Shipments received................
Total (E)......................	Total (E)......................
Stock on hand..................	Stock on hand..............
Bin 1...........cu.ft..........lb.	Tank 1..... ..in. lb.
Bin 2...........cu.ft..........lb.	Tank 2..... .in. lb.
Total (F)......................	Total (F)......................
Consumed ($E - F$)............	Consumed ($E - F$)............

Production:

Stock on hand....................	(P) Production ($M - N$)..........
Materials in operation............	(R) Theoretical production from salt consumed....................
Sales shipments..................	Plant efficiency or yield...........
Total (M)....................	$\frac{(100)(P)}{(R)}$....................
Stock on hand (beginning of period)......................	
Materials in operation (beginning of period).	
Total (N).	

Wadsworth[1] for large-scale manufacture of nitric acid from nitrate of soda, it is assumed that the salt is stored in bins and the oil of vitriol in tanks. The accurate measurement of large quantities of solid materials stored in piles or bins, salt, for example, is a problem that calls for considerable practical ingenuity. Errors in large-scale measurement of bulk material are of two types:

1. Errors in the volume of piles, bins, and tanks.
2. Errors in assuming an incorrect apparent density of the material.

[1] *Chem. Met. Eng.*, **27**, 101, 293 (1922).

Errors in the volume of bins and tanks can be avoided by careful calibration of containers and by using graduated gage sticks. In order to eliminate errors relating to the apparent density of materials, separate determinations should be made on every lot of material received, or at the time of measurement, if there is likelihood of variation during storage. Precision in measuring raw materials should be governed by the nature of the process and bulk value of the materials. In dye manufacture, for example, errors in measurement are relatively serious; consequently, the direct material accounting should be highly developed.

Reliable weigh meters for solids, and weigh tanks for liquids are readily obtainable and simplify greatly the problem of obtaining reasonable precision, that is, within 1 to 2 per cent. Better precision is a practical necessity when the raw materials have high bulk value, as in dye manufacture, or when there are technical reasons for accurate formulation.

In continuous and in semicontinuous processes, there is additional difficulty in accounting for materials, as part of the materials will have gone into the finished product, part will be in process, and the remainder will be in stock. At the end of the inventory period, the quantities must be determined. Making the inventory period fairly long will minimize errors of estimation of materials in process. Furthermore, by dividing each quarter into two 4-week and one 5-week inventory periods, both weekly and monthly average costs can be prepared from the same records. Daily figures would, of course, approach the ideal, but the cost of obtaining them would offset the advantages. The danger of incurring excessive expense in cost accounting is very real. A sane balance must be preserved between accurate but expensive data and those based on guesses.

Recording Direct Labor.—Direct labor is recorded on job cards by a timekeeper, who obtains the following data:

1. Starting time of the workman and the operation or department.
2. Quitting time of the workman and the operation or department.
3. Idle time of the workman.
4. Overtime of the workman and the operation or department.

When reconciled with the time-clock cards, the job cards furnish the data required for pay rolls and for cost distribution. All

other labor is distributed with overhead expense and in accordance with methods described later in this chapter.

Calculation of Overhead.—Indirect material, such as fuel, is weighed or estimated in the same way as direct material. Supplies and repair material are requisitioned and charged to the proper product or department. Such indirect material as that required for general repairs to buildings and service lines is distributed by other methods, as for example, prorated according to the floor area occupied.

Service charges, such as power, heat, and light, can be metered economically if the department is sufficiently large, otherwise, such charges must be prorated. Whether meters are used instead of estimates, or a system of arbitrary distribution of expense, is a matter for individual consideration.

Fixed charges on the investment, such as interest, rent, depreciation, insurance, and taxes, are assigned, as far as possible, to specific products or departments; but a large proportion of such charges always will remain to be prorated. As fixed charges originate in the investment itself, an exact knowledge of the value of plant and equipment is essential. Periodic appraisals, therefore, are desirable. Such appraisals make possible the adjustment of depreciation and other capital accounts and are strongly recommended as a basis for accurate costs. The same appraisals can be used for compiling tax returns, financial statements, and special reports.

Depreciation varies from as low as 2 per cent on permanent buildings to as high as 50 to 100 per cent on pumps, pipe lines, and fittings in exceptionally severe service. A fair range of depreciation rates for all classes of chemical engineering equipment is from 5 to 10 per cent, with an average rate of 7 per cent. An average rate is easily calculated from the component classes of property and their respective rates.

Taxes depend upon local conditions and ordinarily range from $20 to $40 per $1,000 of assessed valuation. Insurance against fire varies from less than one-tenth of 1 per cent on fireproof buildings with full sprinkler protection to about 1 per cent on buildings and equipment in which flammable materials are stored. For use in making cost estimates, a figure of 1½ per cent of the fixed investment will approximate the total of taxes and insurance.

Distribution of Expense.—Distribution of overhead expense is not simple, particularly in the large plant having many departments. The practice of consolidating all expense and prorating it arbitrarily is unsatisfactory, except in small plants in which a considerable investment in measuring devices is not justified. Some typical overhead expenses of plant operation are:

1. Steam.
2. Power.
3. Water.
4. Maintenance.
5. General expenses.
6. Technical service.
7. Rent.
8. Fixed charges.
9. Stores and storage expense.

Distribution of Steam Cost.—In industries such as soap, sugar, and paper pulp manufacture, large quantities of process steam are used. Distribution is obtained through recording meters. Table XVIII shows the heat distribution in a large soap factory before and after installing steam meters. Not only did the meters show the actual distribution, but economies in over-all consumption were effected. In large plants the unaccounted steam will be from 5 to 10 per cent, owing to radiation losses, leaks, and meter errors. Steam for heating buildings can be distributed on a square-foot basis, although a cubic-foot basis is at times preferable.

Distribution of Power Cost.—Electric power cost distribution also should be based on meters. Even in small plants, it will pay to install meters, the readings of which should be checked against the total power consumption as indicated by invoices or by the powerhouse statements.

Distribution of Water Cost.—The chemical industries use large quantities of water, which is easily metered, by departments if desired, thus greatly simplifying the cost distribution. Sometimes water is used as a carrier for materials, as in the paper industry. In such instances, it can be charged as a direct material.

Distribution of Maintenance Expense.—Maintenance work is done on orders that are chargeable to specific departments.

Distribution of General Expenses.—Superintendence, personnel procurement, purchasing, timekeeping, cost finding, employee relations work, restaurant, and the like are general expenses that can be distributed accurately to departments in proportion to the number of employees in each department.

TABLE XVIII.—DISTRIBUTION OF STEAM BEFORE AND AFTER INSTALLATION OF STEAM METERS

Live-steam Distribution, Pounds

	Quarter ending Jan. 1, 1921; steam not metered	Quarter ending Jan. 3, 1925; steam metered
Steam-electric units	24,900,000	40,112,000
Other power units (pumps, compressors, fans, etc.)	17,650,000	19,205,000
Oil and fat distillation	7,250,000	1,917,000
Soap boiling	2,840,000	4,633,000
Glycerin distillation	6,190,000	3,756,000
Factory heating	33,470,000	12,905,000
Sold to tenant		1,905,000
Miscellaneous processes	7,300,000	5,796,000
Total live steam accounted for, pounds	99,600,000	90,229,000
Total live steam unaccounted for, pounds	68,400,000	8,771,000
Total steam generated, pounds	68,000,000	99,000,000
Steam unaccounted for, per cent	40.7	8.9

Exhaust-steam Distribution, Pounds

Mixed-pressure turbine unit	9,300,000	12,177,000
Feed-water heating	11,510,000	1,819,000
Glycerin distillation	9,760,000	....
Factory heating	13,490,000	27,455,000
Soap making		2,337,000
Total exhaust steam consumed, pounds	44,060,000	43,788,000

Distribution of Technical Service Expense.—Large industrial organizations invariably have engineering departments and other technical service departments. That part of the service rendered the production department can be distributed on a time basis. Much of the research and development work, however, is general in nature and is chargeable to administrative expense or to selling expense.

Distribution of Rent.—As a rule, the square-foot basis is used for rent distribution. When the factory is housed in many buildings, various rates, based on the property valuation of each building, should be applied.

Distribution of Fixed Charges.—Fixed charges, such as depreciation, taxes, and insurance, depend on the kind and value of property in each department. Therefore, such charges are readily ascertained.

Distribution of Stores Expense.—Stores expense can be charged to a specific department if storerooms are attached to that department. General storeroom expense can be distributed in proportion to the number of employees in each department. In the chemical industries, raw-material storage is a big factor in expense, usually chargeable, however, to specific departments.

Distribution of Departmental Overhead.—Equitable distribution of general overhead items is perhaps the most difficult task of the industrial cost accountant. In theory, methods capable of great accuracy are possible. The practical cost system, however, must yield reasonably accurate figures with minimum expense, and this has led to several relatively simple methods for overhead distribution.

First, the plant is divided into departments or production areas, in order to segregate operations or processes of similar nature. For example, in a heavy chemicals plant, the chamber acid plant, contact acid plant, muriatic acid plant, acetic acid plant, ammonia oxidation plant, and the alum plant would constitute separate areas, at least for cost-accounting work. The various expense accounts comprising overhead then can be distributed to the individual departments.

When the plant makes only one product or a group of closely related products, distribution of overhead by departments is sufficient. This is true of industries operating on the mass-production principle; that is, when every part of the product is like every other part. Familiar examples in the chemical industries are sulphuric acid, caustic soda, portland cement, fertilizer, gas, wood pulp, sugar, and soap manufacture.

Not all processes, however, yield one product or a group that can be classed singly for cost accounting. In batch processes, such as in dye plants, and in paint and varnish manufacture, two or more products may share the expense of a single department.

In order to distribute the overhead among these products, some basis for accounting is needed, as for example,

1. Direct labor hours.
2. Direct labor cost.
3. Weight, volume, or other unit of output.
4. Production centers.

Distribution on Direct Labor Hours.—On this basis, the direct labor in man-hours is multiplied by a standard overhead rate. The result is the overhead to be allocated to that particular product. This basis is especially useful when labor is a large factor in the total cost.

Distribution on Direct Labor Cost.—The ratio of direct labor cost to overhead can be used as a standard rate, which is then applied to each product. As this rate is based on wages paid for direct labor, it is easy to compute.

Distribution on Basis of Weight, Volume, or Other Unit of Output.—When the products are similar and can be measured in the same units, a definite rate can be applied per unit of product. For example, in grinding paste paints, overhead can be distributed on a gallon basis. In this example, direct labor cost or direct labor hours would be unsatisfactory as a basis, as there is no fixed relation between the capacity of a grinding mill and the labor required to operate it.

Distribution on Basis of Production Centers.—Distribution of overhead on the basis of production centers is sometimes preferred. In this method, the department is divided into clearly defined production centers or operating areas, to each of which an hourly overhead rate is assigned.

In the most approved method of using the production-center rate, the overhead is divided into two parts:

1. Departmental overhead.
2. Production-center overhead, or "superrate."

The departmental overhead comprises such general service items as rent, heat, light, and supervision. Upon this departmental overhead is superimposed the production-center overhead, or "superrate," which comprises such expense incident to operating equipment in the area as power, supplies, maintenance, and depreciation. The sum of the two is the rate to be applied.

Although complex in theory, the production-center rate is simple in practice and has the advantage of accuracy under

shifting conditions. It has broad application to many of the chemical industries, in which operations are divisible readily into well-defined centers corresponding to the various unit operations or unit processes. In general, the greater the importance of equipment in production, the greater will be the reason for employing the production-center base.

Variable Overhead from Variable Output.—The foregoing bases for distributing departmental overhead are predicated on a normal rate of production, say 80 per cent of capacity. So long as actual production is within a few per cent of this normal rate, it is clear that costs will not be much affected. Should production increase to 100 per cent of capacity, however, the overhead then would be excessive. Conversely, at 60 per cent of capacity, it would be too low. Overhead variations due to variations in output have their origin in factory administration. Consequently, such differences should be charged to the profit and loss account. Clearly, the production department should neither be held responsible for the high overhead rate from slack operation, nor be credited with a low rate from operation above normal.

Interest as a Part of Production Cost.—Whether interest on invested capital should be included in production cost is a much-debated question. Each item of capital assets must be considered in relation to similar assets elsewhere in the industry. A safe rule to follow is to include interest whenever the asset varies widely within the industry. Jordan and Harris[1] point out that interest is of two kinds:

1. Interest actually paid out, as on notes, bonds, and mortgages.

2. Interest not actually paid out, as on real estate, equipment, raw materials, and cash.

Interest on obligations is actually paid out, and, as such, it is chargeable to profit and loss. There is no choice in the matter. Considering various assets and applying the foregoing rule, it is reasonable that interest should be charged in the following instances:

1. On real estate, when the equity varies from nothing (in case of rented property) to full ownership. For example, the

[1] Cost Accounting Principles and Practice," Ronald Press Company, New York (1925).

company that pays rent, pays interest indirectly on the property rented, because a normal rental (10 per cent of the appraised market value) not only includes taxes, insurance, depreciation, and maintenance, but interest (profit). The company that does not pay rent, however, has the equivalent expenses, and should, therefore, include interest on the real estate as a part of the cost of doing business.

2. On equipment, when within a given industry, the investment in equipment varies widely. For example, one company may have a small investment in material-handling equipment, relying mostly on manual labor for this work; whereas, another company may have a large investment in such equipment and a very low labor cost. In order to equalize the two cost sheets, interest on this material-handling equipment should be included. Otherwise, the costs would not be strictly comparable.

3. On stored raw materials in excess of normal requirements. These may have been purchased with the hope of a speculative profit, or because some interference with supply was anticipated.

4. On products undergoing unusually prolonged aging. Obviously, this is a storage charge. If, however, the storage is essential to the quality of the product, it is a legitimate manufacturing expense.

Depreciation.—Depreciation can be defined as the unavoidable loss in value of plant, equipment, and materials with lapse in time. According to Kimball[1] the following causes of depreciation are recognized in appraisals of public utility properties—an instance in which depreciation is a very large part of the cost of service:

1. Wear and tear.
2. Physical decay or decrepitude.
3. Deferred maintenance or neglect.
4. Inadequacy.
5. Obsolescence.

Wear and tear is the depreciation caused by physical or chemical action, such as erosion of grinding elements in a mill or corrosion of a pump by acid. Wear and tear can be measured by the maintenance expense required to restore the asset to substantially the original condition.

[1] "Principles of Industrial Organization," McGraw-Hill Book Company, Inc., New York (1933).

Physical decay or decrepitude is characteristic of buildings and equipment that have long stood idle. The term relates to a weakening of the structure, such as the rotting of wood or the corrosion of metals.

Deferred maintenance is expense incurred through neglect to make repairs and denotes a decrease in asset value below the normal for that ordinarily expected with proper care. For instance, deferred-maintenance depreciation may result from neglect to paint buildings with sufficient frequency.

Inadequacy relates to depreciation independent of physical causes or of obsolescence. For example, in the improvement program of a plant, continuous filters might be specified to replace plate-and-frame filter presses. The filter presses would then be depreciated through inadequacy, unless some other application for them could be found in the same plant.

Obsolescence is caused by development of more up-to-date or more efficient equipment that makes scrapping of the old equipment advisable, even though it be in excellent physical condition. For example, in steam-boiler plants, the trend for some years has been toward higher operating pressures. Many of the low-pressure boilers, therefore, have been rendered obsolete.

Calculation of Depreciation.—The basis of depreciation calculations is the expected life of the asset, the first cost, and the scrap value. Then the annual amount of depreciation can be calculated.

Common practice, and the simplest, is to charge off the asset in equal annual installments, in accordance with the equation,

$$d = \frac{V - S}{n}$$

when d = annual amount of depreciation.
V = first cost of asset.
S = scrap value of asset at n years.
n = life in years.

This is known as the "straight-line" formula, because the values derived from it, when plotted, fall on a straight line. For example, a filter press costing \$1,600, and having a scrap value of \$100 after the estimated useful life of 10 years, would be depreciated \$150 a year.

Other methods for calculating depreciation are described in textbooks and handbooks. The straight-line method, however, is used virtually universally in chemical industry. It has been criticized as unsound in principle, but experience indicates that elaborate formulas of depreciation are not required in chemical industry.

Depreciation Rates.—Since depreciation is so important a factor in costs, it is correspondingly important as affecting profits and as affecting taxes based on profits. It is not surprising, therefore, that much thought has been given depreciation studies, by tax-collecting agencies, as well as by taxpayers and their advisors. For instance, the Treasury Department, Bureau of Internal Revenue, in its report entitled "Depreciation Studies" says:

A reasonable rate for depreciation is dependent not only on the prospective useful life of the property when acquired, but also on the particular conditions under which the property is used as reflected in the taxpayer's operating policy and the accounting policy followed with respect to repairs, maintenance, replacements, charges to the capital account and to the depreciation reserve. If the useful life of each of the various classes of assets shown hereafter could be determined precisely, which cannot be done, there still could not be established a standard rate of depreciation for each character of asset unless there existed standard methods of operation and of accounting from which there could be no deviation.

The use of the rates of depreciation based on the probable useful life of the various assets shown hereafter is not prescribed in any particular case, and employees of the bureau, as well as taxpayers, are cautioned against applying them arbitrarily. They are set forth solely as a guide or starting point from which correct rates may be determined in the light of the experience of the property under consideration and all other pertinent evidence.

Being based on the usual experience of property owners, the probable useful life is predicated on a reasonable expense policy as to the cost of repairs and maintenance. However, the probable life shown does not take into account an extended or indefinite term of usefulness due to maintenance and replacement policy. Therefore, in the determination of the depreciation allowance in each case, due consideration should be given the maintenance and replacement policy of the taxpayer and the accounting practice regarding the same.

The estimates of useful life are for new equipment only. In applying the depreciation rates hereinafter shown, consideration should be given

to salvage values, to that portion of the service life already used, and to that portion of the cost or other basis already recovered through prior depreciation or other allowances. Effect should also be given to any unusual conditions incident to the operation of the assets.

It has been found that in certain classes of exhausting assets, obsolescence, rather than ordinary wear and tear, becomes an important factor in determining the allowance. The probable useful life and the rates of depreciation based thereon include an allowance for normal obsolescence. They do not include any allowance for sudden or extraordinary obsolescence, such as is occasioned by revolutionary inventions, abnormal growth or development, or other unpredictable factors which materially lessen the probable useful life of property. . . . Accordingly, the depreciation rates shown should be modified to give full effect to extraordinary obsolescence affecting the useful life of particular assets.

The report then shows the probable useful life and depreciation rate for about 3,000 specific kinds of property, classified into about 40 industries and groups. A few of the items pertinent to chemical industry have been taken from the report and are shown in Table XIX.

As stated by the Bureau of Internal Revenue, there can be no arbitrary assignment of depreciation rates. All the Bureau requires is that the rate claimed by the taxpayer be reasonable and in accord with the conditions of the particular case. For instance, under the classification, "Power generation and electrical equipment," the Bureau assigns a depreciation rate of 5 per cent to "compressors, stationary, all types." This is a reasonable rate for an air compressor of conventional design operating at relatively low pressures and installed in a power plant. On the other hand, consider the high-pressure synthesis industry, in which it has been necessary to design compressors for an entirely new kind of service. Some of these compressors deliver the synthesis gas at pressures as high as 700 to 1,000 atmospheres, a pressure roughly 100 times as high as in ordinary air-compressor service. No one knows whether the new compressors are good for 20 years. Considering, moreover, the rapid progress being made in the industry, they might be quite unsuitable for service 20 years, or even 10 years, hence. In this instance, therefore, a depreciation rate of 10 per cent would be quite as reasonable as 5 per cent.

Relation of Appraisals to Depreciation.—As a check on the depreciation reserve, periodic appraisal of physical assets is

advisable. In this way, proper adjustments can be made, and the management will be assured of having, at all times, rational figures on the books. In a large business, such adjustments may

TABLE XIX.—PROBABLE USEFUL LIFE AND DEPRECIATION RATES

	Probable useful life, years	Depreciation rate per cent
Buildings, masonry or steel frame, factory	40	$2\frac{1}{2}$
Buildings, frame, factory	25	4
Machine-shop equipment	20	5
Tank cars, steel	20	5
Tank cars, acidproof lined	10	10
Storage tanks, steel, oil refinery	20	5
Treating tanks, steel, oil refinery	16	$6\frac{1}{4}$
Tanks, concrete, general service	50	2
Tanks, steel, general service	30	$3\frac{1}{3}$
Tanks, wood, general service	20	5
Boilers, over 50 hp., fire-tube, horizontal	20	5
Engines, steam, low-speed	25	4
Engines, steam, high-speed	16	$6\frac{1}{4}$
Engines, Diesel	20	5
Engines, gas and gasoline	17	6
Electric motors, a.c., below 50 hp	17	6
Electric motors, d.c., below 50 hp	14	7
Electric motors, in acid plant	14	7
Evaporators, multiple-effect	25	4
Stills, ammonia	15	$6\frac{2}{3}$
Stills, cracking	8	$12\frac{1}{2}$
Stills, fire	15	$6\frac{2}{3}$
Stills, steam	15	$6\frac{2}{3}$
Absorption towers	15	$6\frac{2}{3}$
Coke ovens	20	5
Sulphur burners	12	$8\frac{1}{3}$
Pumps, acid, pulp mills	5	20
Piping, stoneware, lead, Duriron	2	50
Dryers	20	5
Centrifugal machines, sugar refinery	25	4
Autoclaves, rubber industry	10	10
Blowers, turbo	15	$6\frac{2}{3}$
Bagging machinery and automatic weighers	15	$6\frac{2}{3}$

total millions of dollars. For example, during the war, huge sums were invested in plant and equipment for munitions manufacture. These investments were made at a time when

construction costs were abnormally high. Moreover, it was impossible to know how long the plants would be in use. Consequently, many companies made thorough appraisals after the war and adjusted their assets according to the deflated values.

An Example in Depreciation.—In any rapidly advancing industry, equipment frequently is rendered suddenly obsolete. Depreciation through obsolescence rather than through wear and tear is likely to predominate when rapid advances are being made in the industry. For example, the *Harvard Business Reports*[1] cites a machine used for grinding rubber scrap. The machine was purchased by a company in 1919 at a cost of $1,000. An annual depreciation rate of 7½ per cent was assigned the machine. In 1922, three years after purchase, changes in the manufacturing process rendered the machine virtually obsolete. It was then used intermittently to grind other materials, and within a year it broke down. The machine had practically no scrap value, and as the estimated cost of repair was $400, it was decided to charge off the current book value, which was $775. The question arose as to how this should be done.

Solution I.—By continuing to charge off the machine at the rate of 7½ per cent annually, it could be depreciated as though it had been in service. This procedure, however, would show a fictitious cost, as the machine was practically worthless even as junk, and the accounts would show an inflation in assets until the end of the estimated useful life, some 10 years in the future.

Solution II.—The machine had been in general use in many departments of a factory in which the total value of equipment was $80,000. Hence, the immediate charging off of $775 would have no appreciable effect on the company's financial condition, and by such a procedure, the adjusted assets would then reflect a true condition. This was the method adopted.

It should be noted that the method adopted in Solution II is entirely in accord with federal income-tax practice. The taxpayer must be prepared to show that any extraordinary write-off is based on solid ground rather than on a mere desire to be conservative. The policy of the government regarding standard equipment already has been discussed. Suppose, however, a

[1] Harvard University, Graduate School of Business Administration: *Harvard Business Reports*, McGraw-Hill Book Company, Inc., New York (1925).

question arises concerning proper depreciation for special equipment of a type never before used in the industry. The taxpayer might claim a depreciation rate of $33\frac{1}{3}$ per cent, because in his *opinion* the equipment will have a life of only three years. The government might agree with the taxpayer, or it might require him to reduce the rate to 20 per cent or perhaps to 10 per cent. Should the equipment become useless at any time during the expected life, the government would then allow the taxpayer to claim the balance of depreciation.

Joint Costs and By-product Costs.—In the mechanical process industries, direct material and direct labor are charged to a specific product without difficulty. Thus, a factory might produce in one shop various machines, as pumps, compressors, gas engines, blowers, and condensers; yet an accurate distribution of direct material and direct labor can be obtained readily. In many of the chemical process industries, however, two or more products result from a process or reaction, and this requires a distribution of cost among the several products. For example, wood distillation gives charcoal, wood alcohol, acetate of lime, tar, and other chemicals, all of which are marketable. To find the proportion of cost chargeable to each of such products is the objective of joint-cost and by-product-cost procedure.

By-products are assumed to be subordinate to the principal product; that is, unable to support, alone, the over-all process cost. As by-products are obtained at no appreciable additional direct labor, or of overhead expense, raw-material cost only is allocated to the principal product and by-products, all other expenses being borne wholly by the principal product. For example, in making refined sugar, molasses is obtained as a by-product, without any appreciable additional expense.

On the other hand, when the products are such that their combined utilization is essential to the success of the process as a whole, they are termed "joint" products. The products of wood distillation, cited previously, are joint products as herein defined.

In the chemical industries, principal products, joint products, and by-products have no fixed relationship. The following are well-known examples:

1. Kerosene once was the principal product of petroleum refining. The low-boiling fractions were practically worthless until

the demand for automotive fuel developed on large scale. At present, gasoline is the principal product, and naphtha, fuel oil, and lubricating stocks are joint products. The coke and still gases are by-products.

2. Charcoal once was the principal product of wood distillation. During the war, however, methanol became the principal product. More recently, owing to competition from synthetic methanol and synthetic acetic acid, the corresponding chemicals from wood have become less important. Charcoal may yet return to its original position of supremacy among the wood-distillation products.

3. The soda industry is an interesting example. In the old Le Blanc process, soda ash was the principal product, muriatic acid was at times a salable by-product, and salt cake was a waste product. When the ammonia-soda process was developed, soda ash became cheaper, and muriatic acid became more expensive, as it was no longer produced in large quantity as a by-product of Le Blanc soda manufacture. The use of muriatic acid, however, as a source of chlorine for bleaching became more and more extensive, and, as a consequence, the Le Blanc process survived. Le Blanc soda then became a by-product, thus reversing the original position of the two products.

With the advent of electrolytic caustic soda and chlorine, the final blow was dealt the Le Blanc soda. Today the first stage of the old Le Blanc process is used to make muriatic acid and salt cake, which normally are joint products. Recently, salt cake, originally a waste product, has become the more important product. So great is the demand for sodium sulphate that large quantities of the natural product are imported from Canada and Chile. Principal consumers are the kraft pulp and glass industries.

By-product Costs.—As stated previously, only the raw-material cost is distributed in by-product costing. According to the procedure outlined in Table XX, the known costs are deducted from the selling prices of by-products *B* and *C*. The residual raw-material costs so obtained are credited to the raw-material cost of the principal product. The cost of the principal product then is built up on this net raw-material cost, and the selling price, including an allowance for administration and selling expense, is shown as a final result.

Joint-product Costs.—Joint-product costing differs from the by-product procedure in that not only raw-material cost, but the total production cost, is distributed among the several products. As outlined by Jordan and Harris[1] the workable bases for distributing joint-product costs are as follows:

1. Chemical analysis of products.
2. Relative weights of products.
3. Current market value of products.
4. Standard ratio.

TABLE XX.—DISTRIBUTION OF RAW-MATERIAL COST TO PRINCIPAL PRODUCT AND BY-PRODUCTS (*Method of Jordan and Harris, "Cost Accounting Principles and Practice"*)

By-product *B*		By-product *C*		Principal product *A*	
Selling price..	$33.00	Selling price.	$11 00	Original raw-material cost	$ 90.00
Less administrative expense and selling expense at 10 per cent on cost	3.00	Less administrative expense and selling expense at 10 per cent on cost	1.00	Less: Credit from by-product *B*......	25.00
	$30.00		$10.00	Credit from by-product *C*.	7.00
				Total credits......	$ 32.00
Less production cost: Labor....... $2 50 Overhead.., 2.50	$ 5.00	Less production cost: Materials.. $1 00 Labor. ... 1.50 Overhead.. 0.50	$ 3.00	Net original raw-material cost for principal product *A*........	$ 58.00
				Extra material cost.	11.00
				Labor cost.........	20.00
				Overhead.........	40.00
				Total production cost.............	$129.00
Balance to be credited to raw-material cost of principal product...............	$25.00	Balance to be credited to raw-material cost of principal product..........	$ 7.00	Add administrative and selling expense at 10 per cent....	12.90
				Add net profit at 10 per cent	14.19
				Selling price.......	$156.09

The first and second bases are the simplest. Economic values, however, are not taken into consideration—a serious deficiency.

Both the third and fourth bases are used widely. The current market-value base, however, has this disadvantage: when the market values are subject to sudden and wide variations, the

[1] "Cost Accounting Principles and Practice."

distributed cost will vary correspondingly. Such variations do not make sense.

Distribution according to standard ratio compensates for every internal and external factor. The ratio is a function not of relative prices in the open market, but of the minimum prices at which a company can sell the products and yet make acceptable profits. Under such a plan, the company with the most efficient process and the lowest costs will not penalize itself.

Assume, for example, that standard values of joint products *A*, *B*, and *C* are calculated to be 30 cts. per gallon, 22 cts. per gallon, and 10 cts. per gallon, respectively; and assume further that for every 1,000 gal. total production, the production of product *A* is 400 gal., of product *B*, 500 gal., and of product *C*, 100 gal., the over-all cost of production being $140.00. The procedure for deriving the costs of the joint products is shown in Table XXI. Profits will, of course, vary as the market prices vary, but the costs will not vary.

In some industries, a by-product, joint product or principal product of a process becomes, in turn, the raw material for another process that yields two or three products. In such instances, the cost procedure merely is repeated. Coal carbonization is an example. Tar constitutes one of the joint products in the primary distillation of coal. In turn, this tar is split further into light oil, naphthalene oil, creosote oil, anthracene oil, and pitch. Moreover, each of these products is refined. For instance, from naphthalene oil come phenol, cresols, wood-preserving oil, and naphthalene.

TABLE XXI.—CALCULATION OF JOINT-PRODUCT COSTS, USING STANDARD RATIO METHOD (*Method of Jordan and Harris, "Cost Accounting Principles and Practice"*)

Joint product	Gallons	Standard value per gallon	Standard values	Per cent of total value	Prorated costs	Cost per gallon
A	400	$0.30	$120.00	50.0	$ 70.00	$0.175
B	500	0.22	110 00	45.8	64.12	0.128
C	100	0.10	10.00	4.2	5.88	0.059
	1,000	.....	$240.00	100.0	$140.00	.....

An Example of By-product Accounting.—The following example of by-product cost accounting appears in the *Harvard Business Reports:* Among the 20 major chemical products manufactured by a certain company were muriatic and nitric acids, which were marketed to the general trade. The salt cake obtained as a joint product normally was worth 80 per cent of the value of the muriatic acid, and the niter cake averaged about 2 per cent of the value of the nitric acid. As no further processing was necessary, the salt cake and niter cake were charged to the finished stock accounts, in which were included handling, storage, and packing expenses. A suitable method of cost accounting, which would justly credit the principal products for the sale of the by-products was required. The following solutions were suggested:

Solution I.—The by-product accounts could be debited, and the main product accounts credited, at a rate based on the current market prices of the by-products. The rate, however, would have to be an average current rate, as the manufacturing accounts were closed monthly, and during that interval, prices of the by-products were likely to vary considerably. Production costs, therefore, for the principal products, would show apparent variations equivalent to the fluctuations in by-product prices, and the comparative month-to-month cost statements would reflect inaccurately the costs of the principal products, muriatic and nitric acids.

Solution II.—The by-product accounts could be debited, and the main product accounts credited, at a standard rate based on a fair average market price for the by-products over a long period, thus eliminating objectionable month-to-month fluctuations in the costs of the principal products. At intervals of a year or more, this standard rate could be adjusted, if desired, to conform to changed market conditions.

Solution II has two disadvantages: (1) The difference between the standard rate for the by-products and current market price is thrown into the profit-and-loss accounts of the main products; and (2) the by-product accounts will show variable profits, or even losses, dependent upon current market prices. These features, however, are not so objectionable as the fluctuations in cost for the principal products in Solution I.

Budgetary Control of Costs.—Within recent years, budgets, or standard costs have become common as a means of controlling cost accounts of all kinds. This is an exceedingly important development, as it tends toward greater stability of costs and, therefore, of profits.

The budget is a supplementary control that has developed from analysis of historic cost records. Through long experience in the manufacture of a product, standard costs can be established, these standards being adjusted as conditions warrant. The important distinction between historic cost accounting and the budget system is that the former shows a cost after the work is performed, whereas the latter fixes a standard of cost prior to performance. Budgetary control, therefore, makes possible an immediate correction of operating abnormalities.

Historic cost accounts never will be displaced, as they constitute the record of actual performance. Moreover, historic costs are necessary in order to establish rational standards. Why standard costs have not been used more generally in production control is peculiar, when it is considered that the first test of a proposed process is a cost estimate. This estimate, rough though it may be, is a budget, and the principle of the budget is just as applicable to existing processes as to proposed processes.

Budget control in cost accounting requires a close study of the manufacturing process in order to determine what constitutes reasonable cost standards. Standards are set for direct raw-material cost, direct labor cost, and for each item of overhead. Standards relating to material and labor should be based on quantities, rather than on prices and wage rates; otherwise, the standards frequently will require adjustment to meet changing conditions.

Table XXII shows a raw-material budget calculated by Groggins[1] for producing nitrobenzene. Likewise, detailed budgets can be set up for the other elements of production cost. It is not sufficient, however, to set up the budget only for operation at full capacity. Over a period of years, a plant may be operated at anywhere from 25 to 100 per cent of capacity; or it may be shut down completely. To be most useful to the management, a

[1] "Aniline and Its Derivatives," D. Van Nostrand Company, Inc., New York (1924).

budget must include standard costs for any operating condition that is likely to arise. Direct material is virtually the only unit cost element that will not vary as the output varies. Even direct labor cost will vary with output, since below a certain output it is not feasible to reduce personnel further. Similarly there are

TABLE XXII.—BUDGET FOR NITRATION OF BENZENE TO NITROBENZENE
(from Groggins, "Aniline and Its Derivatives")
Basis, 100 lb. of Nitrobenzene

Theoretical yield on benzene		157.7 per cent
Standard yield for determining costs		153.5 per cent
Debits:		
Benzene	65.15 lb. at 3.00 cts	$1.95
Sulphuric acid	71.00 lb. at 0.75 ct.	0.54
Nitric acid	55.00 lb. at 6.00 cts	3.30
Sodium carbonate	1.00 lb. at 2.00 cts	0.02
Total raw-material cost		$5.81
Credits:		
Sulphuric acid in waste	69.0 lb. at 0.5 ct	$0.345
Nitric acid in waste	0.9 lb. at 5.0 cts	0.045
Total credits to raw-material cost		$0.390
Net raw-material cost		$5.42

minima for such service costs as power and process steam. For instance, the power required to drive an empty mill, such as a ball mill, may be a large proportion of the power required under full load. A workable budget system, therefore, must include standard costs covering a wide range of operating conditions.

The necessity of first having accurate and representative cost data with which to work is obvious. No attempt should be made to set up standards until the machinery of cost accounting has been working smoothly for a sufficient length of time.

CHAPTER XII

PATENTS

In an address before the Centennial Celebration of the American Patent System, Washington, D. C., Nov. 23, 1936, Thomas Ewing, a former commissioner of patents, said:

"The American Patent System was in large part, but only in part, developed in this country. England has had a patent system since the Statute of Monopolies which was enacted in the reign of James I, in 1623, as the culmination of agitation running for fully 300 years."

Although the American Patent System in its present essentials dates from 1836, the first patent law was enacted in 1790 during President Washington's administration. Thomas Jefferson, who was then Secretary of State, participated in this enactment. The Constitution, it should be noted, provided for patents:

"The Congress shall have power . . . to promote the progress of science, and the useful arts, by securing for limited times to authors and inventors, the exclusive right to their respective writings and discoveries."

Definition of Invention.—What constitutes invention? The Supreme Court[1] has said:

"The truth is the work cannot be defined in such manner as to afford any substantial aid in determining whether a particular device involves an exercise of the inventive faculty or not."

In order to obtain an American patent, however, the applicant must satisfy the Patent Office that he has created, devised, or discovered something new and useful. As specified in Section 4886, Revised Statutes of the United States

Any person, citizen or alien, who has invented or discovered any new and useful art, machine, manufacture, or composition of matter, or any new and useful improvement thereof, not known or used by others in this country, and not patented or described in any printed publication in this or any foreign country, before his invention or discovery thereof,

[1] McClain *v.* Ortmayer, 141 U. S. 419, 427: 1891.

and not in public use or on sale for more than two years prior to this application, unless the same is proved to have been abandoned, may, upon payment of the fees required by law, and other due proceedings had, obtain a patent therefor.

Definition of Patent.—Under the American Patent System, a patent is a written contract between the inventor and the United States Government wherein the inventor discloses his invention so clearly and fully that anyone skilled in the particular art can practice it. In consideration for such disclosure on the part of the inventor, the government grants the inventor a monopoly of manufacture, sale, and use for a period of seventeen years.

Rights of the Inventor.—The various rights of the inventor have been defined in statutes. Among these rights are the following:

1. The patent is granted to the first inventor, not to the first applicant.
2. Priority goes to the inventor who first conceives the idea of the invention and who exercises reasonable diligence in reducing it to practice, as against the inventor who has a later date of conception, though an earlier date of reduction to practice.
3. The term of the patent begins with the date of grant, not the date of filing application.
4. The right to a patent is not dependent upon the favor of anyone.
5. The applicant is required to file an oath as to originality at the time of filing application, thus affording added protection against those who might abuse confidence and attempt to steal the invention.
6. The patent right is assignable in whole or in part by the patentee, thus enabling the inventor to finance development or to sell his right unconditionally.
7. In the event of premature death of the inventor, his legal representatives may file application.
8. In the event of issuance of a defective patent, the patentee has the right of reissue.
9. In the event of infringement, the patentee or his assignors, or his legal representatives may obtain satisfaction as in damages, profits, or "reasonable royalty," or as an injunction.

Organization of the Patent Office.—The Patent Office organization is divided into 65 separate divisions, each of which is

responsible for a specific class of the art, and each of which is virtually autonomous. The numbers and subjects of the divisions dealing largely with chemical industry and chemical engineering follow:

6. Carbon Chemistry.
15. Glass; Plastic Block and Earthenware Apparatus; Plastics.
19. Furnaces and Stoves; Fuel Burners.
31. Gas, Heating and Illuminating; Mineral Oils.
32. Gas and Liquid Contact Apparatus; Heat Exchange; Gas Separation.
43. Medicines; Bleaching and Dyeing; Explosive Compositions; Sugar and Starch.
46. Evaporators; Fluid Sprinkling; Fire Extinguishers; Boilers, Heating Systems.
49. Check-controlled Apparatus; Ventilation; Driers; Liquid Purification.
50. Varnish; Coating Processes; Carbohydrate and Condensation Products; Cellulose; Rubber.
51. Radiant Energy.
56. Electrochemistry; Laminated Fabrics; Paper Making; Substance Preparation.
59. Chemistry; Fertilizers.
64. Acetylene; Distillation; Gas Mixers; Oils, Fats, and Glue Liquid Coating Compositions; Fuel; Alcohol.

As of the end of 1937 the personnel of the Patent Office numbered 1,360, including 694 patent examiners of various grades. More than two million United States patents have been issued, and the present rate of issue is approximately one thousand a week.

Patent Office Procedure.—Patent Office procedure is described in "Rules of Practice in the United States Patent Office, Revised." This publication, which is available free, contains also the list of fees for filing and for other actions.

The following discussion of procedure is intended only as an outline of the more important points. Although an inventor may act as his own attorney, such a course is inadvisable. It is significant that experienced inventors do not attempt it, however well informed they may be regarding the fundamentals of the patent law. Although they work closely with their attorneys, they work as technical advisers, not as attorneys. If an invention is worth protecting, then it would seem only wise to engage qualified legal counsel.

The Patent Application.—The application for United States Letters Patent is made to the Commissioner of Patents, and comprises the following parts:

1. The Petition, in which the inventor prays for the issue of the patent.
2. The Specification, which contains the following parts:
   a. Preamble, an identification of the invention and inventor.
   b. General statement of the nature and purpose of the invention.
   c. Drawings, models, or samples if essential to the description.
   d. Statement of the invention in detail, including, preferably, examples showing reduction to practice.
   e. Statement of what is claimed to be the scope of the invention.
   f. Signature of the inventor.
3. The Oath, in which the applicant swears that he believes himself to be the original inventor; that to the best of his knowledge and belief the invention has not been in public use, or offered for sale in the United States for more than two years prior to his application; or published or patented in any foreign country for more than two years prior to his application.

After having been filed, with the filing fee of $30.00, the application is assigned to the appropriate division of the Patent Office. It is then the duty of the examiner to search all patents, periodicals, and books in which pertinent art is believed to be disclosed. References which anticipate any of the claims are cited, and the corresponding claims may be rejected, subject to argument between the attorney and the examiner. This may result in rejection, amendment, or the substitution of other claims. Normally, the final agreement between the attorney and the examiner is reached after several actions. If, however, the attorney and the examiner cannot agree as to the claims, the examiner "finally" rejects the claims and the applicant will abandon the case or else appeal to the Board of Appeals of the Patent Office and then to the Court of Customs and Patent Appeals.

Interferences.—When two or more conflicting applications are on file and at least one is otherwise ready for allowance, a proceeding called "interference" is instituted in the Patent Office, in order to determine which of the two or more applicants is the

prior inventor. The issues of the interference are priority of invention and granting of the claims thereon. In order to determine priority, the Examiner of Interferences considers the testimony by the parties, each of whom is first required to file a statement under oath, specifying the date of conception of the invention, of reduction to practice, and of any disclosure of the invention to others. No disclosure of the testimony is made until all the parties have filed such statements.

An application may be in interference with another application or with an issued patent. Should the applicant for a patent prevail in an interference over the issued patent, the claims mistakenly allowed may be disclaimed by the patentee.

Appeal from the action of the Examiner of Interferences may be taken to the same tribunals as in other cases.

Infringement.—Anyone who practices an art or who makes, uses, or sells a composition of matter or a machine for which a patent has been issued and who has knowledge of the existence of the patent, may be held responsible for infringement.

In remedy for the infringement of a patent, the courts may grant (1) an injunction, (2) recovery of damages, profits, or a reasonable royalty. Injunctions may be preliminary (pending a final decision of the courts) or permanent. Damages may be awarded when the plaintiff can show that the infringement has caused a definite loss of business profits which otherwise would not have been suffered. Profits may be awarded when the plaintiff did not suffer a loss in his own business, but when he can prove that the defendant, by virtue of the practice of the patent has made certain profits or savings. When the plaintiff cannot prove the exact amount of profits or savings made by the defendant, but can, however, prove that the profits or savings are substantial, the award may be a "reasonable royalty," that is, such an amount as the defendant could reasonably have been expected to pay the plaintiff for the use of the patent under a royalty agreement.

In the event that the defendant has infringed deliberately and without any substantial defense, the plaintiff may be awarded in damages as much as three times the actual loss proved.

Relations between Employer and Employee.—A patent is valid only when issued to the actual inventor. An employer, therefore, who is not the actual inventor, can have no title in

the patent except by assignment. An employer is the inventor only if he actually conceives the idea, or contributes to the conception. The fact that an employer hires an employee to invent a specific thing does not make the employer an inventor.

The employer, on the other hand, has certain rights. Thus, when the employer has conceived an idea and hires a technical expert to reduce the idea to practice, the employer is the sole inventor. When the employee is hired expressly to make an invention, he is bound to assign any patent on such invention to his employer. Usually the relations of research personnel to the employer are defined by written agreement, insofar as patent rights are concerned.

When an employee who has no agreement with his employer regarding invention makes an invention while using the facilities and time of his employer, then his employer is entitled to a free nonexclusive license to use the invention. Such nonexclusive license is called a shop right. Ownership of the patent, however, resides in the employee.

Negotiation of Inventions.—An inventor, working independently, need have no fear as to his rights and as to his proper course of action, provided he has competent counsel. He will be advised how to apply for a patent, how to protect his rights as a patentee, and how to negotiate assignments and license agreements.

Contrary to popular belief, the large corporation perhaps more often than the independent inventor needs to be watchful when negotiating inventions. A large corporation operating in a technical field, such as chemical manufacture, is likely to have many inventions offered to it by independent inventors. The matter would be very simple if such offers were made only to the corporation's attorneys. Usually, however, the individual starts to negotiate or discloses his invention to some employee outside the corporation's legal department. If he does so before securing his patent or before filing the application, the corporation may find itself in an embarrassing situation. Not infrequently ideas are conceived simultaneously, or nearly so, particularly if the field of the invention is active. Thus, the corporation may have offered to it or disclosed to it, an invention identical with, or similar to, one already conceived but not yet embodied in a patent application. In that case, the individual

might readily conclude that the corporation had stolen his invention.

In the interest of the individual and the corporation, inventions should not be negotiated until they are protected properly. The employee of the corporation, when approached by an individual who desires to negotiate an invention should refuse to listen to a disclosure of the invention until he is satisfied that the invention is protected by a patent application or by an issued patent.

Notebook Records.—Too frequently technical men regard the keeping of laboratory notebooks as a necessary evil arising merely from the ultimate necessity of writing a formal report. However, this reason and the fact that the keeping of full and intelligible records of ideas and experiments is the businesslike thing to do are not the only and, frequently, not the most important reasons for properly kept laboratory records. One can never be sure beforehand whether an idea or an experiment will subsequently be the subject of a patent application that may be involved in an interference or, as a patent, be the subject of litigation. In either case, the proof of conception and reduction to practice is a matter of prime importance in which the character of the original notebook records is critical. The only safe practice, therefore, is to keep all technical records in accordance with standards which patent considerations make necessary.

The following rules for keeping research notes have been found to be satisfactory:

1. Write all research notes in ink and in bound notebooks.
2. Enter all notes in chronological order.
3. *Sign* and *date* the notes at the end of each day's work.
4. Keep the notes in a secure place at all times.
5. Review the notes and related work once a week with a responsible person familiar with, but not personally interested in, the particular research under question, and have the person sign and date the notes after each weekly conference.

The purpose of Rule 1 is to make for permanency and to minimize the chances of loss of the notes. Ink lends to the evidentiary value of notes, because ink is not easily erased, and erasures are always regarded with suspicion. Loose-leaf notes are unsatisfactory, because of the possibility of loss and the ease with which pages may be substituted.

The purpose of Rules 2 and 3 is to enable the attorney to establish that the work was always done in the order noted, and on the dates alleged, and by the person alleged to have done the work.

Rule 4 is not only a common-sense custom, but valuable because an attorney is always faced with proving the custody of any documentary evidence offered in court.

Rule 5 enables the attorney to establish corroboration of the invention. A corroborating witness must be disinterested (one of several joint inventors is of no value for this purpose) and intelligent (that is, capable of understanding the invention and remembering at some later date that it was explained to him in considerable detail).

An inventor in an interference must prove his *conception* of the invention by his own testimony and the testimony of at least one corroborating witness. Conception is mental visualization of every element of the invention with sufficient clarity to enable the inventor to explain the invention to someone else. The inventor is also required to prove that he has *reduced* the invention to *practice*. Reduction to practice is successful operation (of a process or machine) or identification or use (of a composition of matter). The inventor's evidence of reduction to practice must be supported by the testimony of at least one corroborating witness. Because of the necessity of proving both conception and reduction to practice, a technical man should report in his notes and have witnessed, not only actual work performed, but also any inspiration or conception which may occur to him.

For a more comprehensive discussion of patents and patent law, the reader is referred to the "Chemical Engineers' Handbook" by John H. Perry.[1]

Significance of the Patent System.—The American patent system offers rewards to the inventor and to those who back him. The public benefits from the many new and useful products thus developed, and from the lowered cost and improved character of old products. New industries are created and immense numbers of workers receive profitable employment. Finally, upon the expiration of the patent, any member of the public can use the entire invention free from the rights of the inventor and his assignee and can enjoy its benefits indefinitely.

[1] McGraw-Hill Book Company, Inc., New York (1934).

The present system has encouraged invention and made it possible for the individual inventor safely to disclose his idea to those who are in a position to help him develop it. Were it not for this protection, the stimulus to invent which now exists would be lessened considerably. The great difficulties which would face the inventor in the form of limited resources and inadequate facilities, the problem of maintaining the secrecy of the invention and trying to keep others from profiting at his expense during the development of his idea, would tend to discourage invention and thus deprive the public of countless necessities and luxuries which it now enjoys because of the incentives created by the patent system.

CHAPTER XIII

INDUSTRY AND THE CHEMICAL ENGINEER

The World War marked a change in the status of the chemical engineer. Before the war he was an important factor in design and construction, and in developing production systems. Research, however, was not recognized generally as a major industrial function.

The war revealed glaring weaknesses in the national economy. It revealed a deficiency of dyes, medicinals, photographic chemicals, nitrogen products, camphor, and potash, to name a few specific examples. More serious, however, it revealed a deficiency of experienced technologists and research workers.

Some years elapsed before the lessons taught by the war were generally applied. Even as recently as the depression of 1921, the research departments of many industries were among the first to be curtailed, if not lopped off altogether. In the depression beginning in late 1937, the curtailment of research was certainly no greater, and probably was much less than in other activities.

Indicating the tremendous increase in the volume of research, the number of research laboratories in 1920 was 350; in 1927 there were 1,000; in 1933 there were 1,575; and it is estimated that in 1937 there were nearly 2,000 research laboratories employing 40,000 technical personnel and spending nearly $300,000,000.

Present Trends in Industry.—If an old order is passing, what is taking its place? The fact was cited that in 1937 expenditures for industrial research were about $300,000,000. By no means does this figure, large as it is, represent a ceiling. In 1937 the research expenditure in manufacturing industry as a whole probably did not exceed ½ of 1 per cent of the normal dollar volume of sales, whereas in a progressive branch, such as chemical industry, the normal research expenditure is between 2 and 3 per cent of sales. Thus, a continued upward trend in research expenditures may be expected. One is justified in concluding

that industry's research budget is only one-fifth of a reasonable potential.

Selling and Purchasing.—In marketing, many opportunities for the technical man are opening up. In 1937, the chairman of a leading company in the air-conditioning industry remarked that the rate of growth of his organization was limited only by an ability to employ and train engineers for the sales organization. Several of the oil companies feature in their advertising that their lubrication experts will survey industrial plants in order that lubrication service may be improved and costs reduced. These experts are engineers, yet their major responsibility is to sell goods. Similarly, the chemical companies employ engineers and chemists to sell such products as dyes, commercial explosives, and plastics.

The number of technical men employed in industrial sales work is not known. Probably there are 10,000 or more. Technical men are employed not alone to sell products and services; they are employed to develop new applications of products and services; and to investigate and adjust the thousand and one difficulties that arise in a complex industry. For example, if the dye that a textile manufacturer uses fades when it shouldn't fade, it is up to the seller of the dye to find the answer. Perhaps the wrong dye was used; or perhaps the dye, although correct for the purpose, was applied wrongly. In any event, the textile manufacturer is vitally interested in correcting the trouble, as several dollars' worth of dyes may affect the salability of several hundred dollars' worth of fabric. No amount of sales talk can substitute for sales technology.

Not only research, production, and marketing, but many other functions of the industrial organization are open to the chemical engineer. Purchasing, which is merely selling as viewed from the other side of the desk, is a promising field. Who should be better fitted to purchase raw materials and equipment than the man familiar with their manufacture and application? The industrial purchasing agent has a highly technical job.

Patent Law.—Patent law is another field for the chemical engineer. The opportunities are no less promising, though less numerous, than in marketing. United States patents are issuing at the rate of 1,000 a week, and of these a large proportion is in such highly technical fields as chemical processes, chemical

compositions, and chemical apparatus. Nearly 700 attorneys of various grades are employed in the Patent Office, and several thousand more are employed in the legal departments of corporations and in law firms. Most of them possess both technical and legal training. As the rate of issue of patents is increasing, especially in the fields mentioned, there is no doubt concerning the future of patent law. It is exceedingly bright.

Industrial Relations.—Another trend is the greatly increased emphasis on employee relations. There are evidences of it in government, as witness recent legislation affecting old-age pensions, unemployment insurance, and collective bargaining, as well as sweeping legislation affecting wages and hours. In 1937 there was nation-wide strife not only among employer and employee groups, but among labor organizations themselves. This was not a new phenomenon; it was merely the latest recurrence of an old phenomenon. Unquestionably, employee relations in industry can be improved. A problem exists, and it is a problem that is worthy of the keenest talent that the country possesses.

The field of employee relations, therefore, presents a real opportunity for the man who is interested deeply in people as well as in the technical aspects of industry.

Public Relations.—Close to employee relations is the field of public relations, that is, contacts between an industry and the various groups with which it deals. Legally, there is such a thing as private industry. Actually, the affairs of industry, particularly as represented by the large corporations, are matters of widespread public interest.

Information regarding a corporation's pay roll, the number of employees, net earnings, dividend payments, ownership of stock, technical developments, new products, price reductions, creation of jobs, expenditures for plant expansion and improvement, introduction of employee benefits—all are matters of interest to the public. Not only the activities as such, but the extent to which the public is informed regarding these activities determines, in the long run, the public's attitude toward a company and toward industry as a whole.

The public interest in business and industry, especially "big business," springs from more than an idle curiosity. America is a nation of capitalists as much as a nation of working people.

Thus, at the end of 1937, there were 15,000,000 owners of stocks and bonds, 44,000,000 savings accounts, 64,000,000 holders of life insurance policies, 14,000,000 owners of homes, and 25,000,000 owners of automobiles. Small wonder that the public is interested in the corporations upon which much of this wealth is based. The need, therefore, for people who can interpret industry to the public is increasing. It is one of the important trends of the times. Public relations is a large field and utilizes not only the press, but all other organized agencies of information, including approximately 2,000 daily newspapers, 11,000 weekly newspapers, 6,000 other periodicals, 700 radio stations, 24,000,000 radio-equipped homes, and 20,000 motion-picture theaters.

Achieving Success in Industry.—Foremost is the factor of individual performance. There is much confusion on this point. Certain desirable qualities, such as industry, dependability, persistence, initiative, and ingenuity have been stressed so much that the ultimate objective is often obscured. That objective is the contribution of something of more than ordinary value to the business. It may be a technical invention, it may be an idea, it may be an exercise of leadership.

What constitutes a valuable contribution? If an employee does merely what he is told to do, or what he is expected to do, then no matter how well done, that alone is insufficient to bring the highest rewards. As soon however, as his performance exceeds the normal expectation for one of his position, then it calls for a higher-than-average reward. The better-than-average chemical engineer is an avid investigator. From the most promising leads he develops positive, as well as negative, recommendations. This procedure continues until a problem is solved or is discontinued. No one issues orders to such a man, except in the most general terms. Actually, he issues orders to himself and to his superiors, because each forward step that he takes indicates to himself and to his superiors what should be done next.

A second factor relating to progress is the position of the industry with which the individual is associated. Is the industry on the upgrade, is it on the downgrade, or is it in a chaotic condition? It is just common sense that, if an industry prospers, at least some benefit should accrue to all companies and individuals identified with the industry. For example, the synthetic organic chemicals industry in this country is on a definite upgrade.

During the past 10 years, when industry in general made little or no forward progress in terms of dollar volume of output, the value of synthetic organic chemicals output increased about fivefold. Other industries on a similar marked upgrade are rayon manufacture and plastics manufacture. Thus, in the year 1935, the dollar value of all manufactured goods was only 71 per cent of the 1925 value, whereas the dollar value of rayon production was 210 per cent, and of plastics production 128 per cent of the 1925 dollar value.

A third factor is the position of the company within the industry. Is the company growing faster, slower, or at about the same rate as the industry of which it is a part? What is the company doing to advance itself and to advance the industry? What is it doing technically with respect to the development of new products, improved products, new processes, improved processes, new uses, better equipment? How much money is spent for research, and what is the relation of such expenditure to the size of the company? What important inventions have been originated? These are technical matters. Equally important is the company's attitude toward its employees, the public, and the stockholders. Does the company believe in high wages and employee benefits, and has it a good record regarding employee relations? Is the company open in its relations with the public, and does it strive earnestly to inform the public regarding its products, operations, and policies? What caliber of men comprise the executive staff and board of directors? Finally, what has been the company's financial record during the past 5 years or, better yet, during the past 10 years? Such facts as net earnings, gross sales, ratio of net earnings to gross sales, working capital, ratio of current assets to current liabilities, net worth, and ratio of net earnings to net worth are valuable yardsticks. A tabulation of such data may reveal some surprising trends.

The position of a company within its industry is very important. How unfortunate are the consequences when a young man becomes associated with a company that is unprogressive! His efforts, even if appreciated, cannot always be rewarded adequately. His training suffers. He becomes discouraged and may even lose his job.

A fourth factor is the size of the company. Many times the question is raised among students, "Shall I go with a small com-

pany or a large company?" Though much discussed, this is a question that remains unanswered in the minds of thousands of students.

The fact that every large business once began as a small business is significant, as is the fact that many tasks can be done better by large business than by small business. There is a place in the national economy both for small business units and for large units. For example, in the paint business, there are hundreds of small companies. In many instances these small companies are well managed and turn out a good product. In the nitrogen fixation business, however, there is no such thing as a small company. A large amount of capital is required to operate economically. In the steel industry it has been stated that $50,000,000 dollars is the minimum capital required to set up a well-balanced business.

The answer to the question boils down to a matter of individual aptitudes and temperament more than anything else. In order to be successful in a small company, a man must be unusually resourceful and versatile. A small company is managed by a small group—sometimes one man does most of the creative work as well as most of the executive work. There is nothing "fancy" about the small company. Its objective is to do one thing, or at most, a few things, supremely well. Frequent personal contact between the president and his workmen and his customers supplies the magic touch that spells success. On the other hand, the small company necessarily has its eggs in one basket, so to speak, and a single unfavorable turn of events may mean disaster. The employee in a small business can acquire a broad experience in relatively few years, and the management is well aware of his performance. His material rewards, however, are unlikely to be large.

For the technical man of the creative type, the large corporation affords excellent opportunities. The aids and encouragements afforded the "idea man" in a large corporation are tremendous. At his command are equipment, ample funds, and a wide variety of technical specialists. Powerful incentives to performance are ever present.

In one company there are approximately 1,200 research men, organized in 28 laboratories and engaged on hundreds of major projects. Here, no matter how narrow a man's interests there is

a place for him, yet the opportunity in terms of accomplishment and financial rewards is hardly without limit. For rewards are based, not only on the nature of an achievement, but on the opportunity for capitalizing on the achievement. For example, assume that a company is producing 100,000 tons of a certain product a year. A saving of $1.00 a ton in cost would amount in the aggregate to the substantial sum of $100,000 a year. The same saving per ton, if applied to a company producing 1,000 tons a year would amount to only $1,000 a year. In both cases the achievement is identical, if measured as a technical achievement. When measured on an economic scale, the achievement in one case is 100 times as important as in the other case. That is the reason why large corporations can afford to pay, and do pay, their technical directors compensation of the order paid to production directors and sales directors.

A fifth factor relates to the nature of the job. As typified by the production and sales organizations, the man who possesses executive potentiality will move ahead more rapidly than a man in a staff or specialist job. Statistics based on the earnings of hundreds of men prove this statement. This is simply another way of stating that, on the average, executive work is the highest paid work. This does not mean that everyone should strive to become an executive. It merely indicates a condition.

Evolution of the Technical Graduate.—If the technical student could picture himself at the end of 10, 20, or 30 years, it would give him a clearly defined, realistic goal, which would affect his attitude toward his college work and toward his early experience in industry.

The following facts are based on a study of 700 graduates of one of the largest and oldest technical schools in the country. The facts apply, however, to chemical engineers, as well as to technical graduates generally. At the end of the first year from graduation, 70 per cent of these men were engaged in purely technical pursuits, as, for example, in computation, drafting, chemical analysis, design, and operation; 5 per cent were engaged in executive work; 18 per cent were engaged in teaching; and 7 per cent were engaged in other occupations, mostly commercial work such as sales.

At the end of 10 years, only 31 per cent were engaged in purely technical work, but the executive group had increased to 50 per

cent. The teaching group had decreased to 10 per cent, and the miscellaneous commercial group had increased slightly to 9 per cent. Among the executive group are included such positions as foremen, superintendents, department heads, chief engineers, research directors, and sales managers, as well as presidents, vice-presidents, general managers, partners, and proprietors.

At the end of 20 years, those engaged in purely technical work decreased still further to 25 per cent, and the executive group had increased to 56 per cent. The teaching group had decreased to 5 per cent and the miscellaneous commercial group had increased to 14 per cent.

At the end of 30 years, at which time the average age of the group was 52 years, those engaged in purely technical work had decreased to 17 per cent, whereas the executive group increased sharply to 70 per cent. The teaching group was practically unchanged at 6 per cent, and the miscellaneous commercial group had decreased to 7 per cent.

This study shows that, at the end of 30 years, 7 out of every 10 technical graduates are engaged in executive work. This is not surprising when one considers that modern industry is so complex technically. It is logical that the men who have devised new products, new processes, and new equipment be called upon to manage the industry resulting therefrom. The day of rule-of-thumb management is passing rapidly. A profession of management is taking its place.

INDEX

D